WHAT, HOW AND WHY:

Reconceptualising Science Education

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ABSTRACT

This thesis proposes a reconceptualisation of science education. Compulsory science education should be seen in the broad context of general education, and science education should share the social goal of enhancing democratic society. The reproduction and transformation of social institutions is affected by the way people live their lives, and people's daily decisions and actions are shaped by their world-view. By developing citizens with a science-compatible world view, and with the ability to think rationally and critically, science education can contribute to social change .

The way science is portrayed to learners will influence their world-view. Science cannot be characterised by a simple, fixed method, nor is it just an alternative way of viewing the world. Science is best presented as a way of thinking, and as a conscious search for the truth. Citizens' critical attitudes and sense of justified skepticism will be suppressed if science education reinforces a positivist view of science. Alternatively, post-modernist teaching pushes skepticism to a level where it will destroy people's belief in 'meta narratives' such as the democratic project.

Learning science involves gaining a measured commitment to a theoretical position, and also involves knowing when to change this commitment. In the classroom, teachers may make moderate use of the authority of science, providing they are inducting children into science and not indoctrinating them. There is a fine line between induction and indoctrination, and science education outcomes depend on teachers' decisions made in a very complex environment. Teachers often face legitimate but conflicting educational demands, and this creates a 'dilemma' for which educational theory alone is unable to provide solutions. A model is presented in which there is considerable scope for teacher autonomy, and for teaching decisions to be based on craft skills and local knowledge. However, 'developmental research' does offer a mechanism for advancing pedagogical knowledge and teacher wisdom.

The thesis concludes that, despite criticism of the present New Zealand science curriculum, and despite primary teachers' lack of expert scientific knowledge, there is potential for progress. However, progress is contingent upon the provision of clear goals for science education and, particularly for primary school teachers, the provision of appropriate support.

CHAPTER 1 PUTTING THE THESIS IN CONTEXT

1.1: A Personal Note

Work on this thesis was started shortly after I took over the science education department at Christchurch College of Education. At that time I was heavily involved in the development of pre-service courses for both primary and secondary students, and this seemed a natural source for the thesis topic. In order to narrow the scope, the initial topic was set as a report on the development and evaluation of a pre-service training programme for primary science teaching.

I had written most courses from scratch but soon became aware that much of this had been done from a gut feeling rather than from an articulated theoretical base. Clearly, I needed to know what good science in the primary classroom was if I was to prepare students to go and teach it, and this became the new focus. Previously I had travelled to the other colleges and spent time in their science departments. Many of the ideas and courses matched my own - to help students who knew little science to gain confidence in teaching the subject; to teach students some basic science content within a very short contact time (and without putting them in a failure situtiion); to persuade students to give children a science programme that was hands-on; and for us to give students the skills to teach in a manner that took into account the children's existing knowledge (and that treated children's views with respect). Largely, these views and aims corresponded with the 'constructivist' view of teaching and learning; a view that was later scrutinised by Michael Matthews (1995) and others. While Matthews' interpretation of constructivists' aims and methods, and his manner of conducting the debate, could be viewed as extreme, I came to share enough of his concerns to reject constructivism as the foundation on which to build science education. Constructivism provides some alternative teaching techniques but it is not the answer to all our prayers.

While constructivism offered answers in the form of ways to teach science, I suspected that the question of what was good science in the primary school had not been seriously asked. However, one of the things I learned from the debate over constructivism - which is, at heart, heavily philosophical - was that the answer to what constitutes good primary science would come from asking the question, what is good science? Unfortunately, even a cursory reading of the literature of philosophy of science is sufficient to see that there is no clear answer to this question. Is science a omnipotent method of finding out the true nature of the universe? Or is science a cynical way of raising the mystique of scientists' particular (but by no means priviledged) notions of the way the world works, and of advancing the selfish cause of scientists? Fortunately there are alternatives to such simplistic (positivist) and excessively skeptical (post-modernist) views of science. One alternative view lies in the broad band of 'realist' science, perhaps best described as the science of scientists, rather than the science of philosophers or sociologists [which is not to deny that there are philosophers and sociologists who hold realist views of science]. The bolder versions of the realism hold that science is about finding the truth, and in Chapter 8 I will explain why I favour this view as the underpinning for science education.

While thinking of the processes of education occuring in the classroom, it struck to me that I did not really know what the purpose of education was. This was particularly so for universal and compulsory schooling which is a relatively recent phenomenon [and even today a requirement that is only thoroughly established in the industrially advanced nations]. Clearly, education has a function of socialisation, but this only raised further questions about the nature of society, about the relationship between individuals and social institutions and, in particular, about the nature of capitalism.

At one stage in its evolution, this thesis was cynically entitled 'Science Education and the Meaning of Life'. It seemed at the time that such was the question that I would eventually face in my quest for a theoretical foundation on which to base science education. I did manage to avoid delving into the meaning of life, but work on this thesis has led me to question the nature of modern science, the place of science education within general education, the role of general education in society, the nature of our social institutions and the mechanisms for social change. The thesis topic finally evolved as finding a coherent rationale for compulsory science education. In terms of the New Zealand situation, this refers to science for Years 1-10 (Level 1-6 in the curriculum document). Of particular interest are Years 1-8 because these are where the foundations for science learning are established, and because this is where teachers are least likely to have specialist science knowledge. The result is a coherent justification for teaching science to all children, and a theoretical model for guiding and evaluating science teaching. Without wanting to sound presumptuous, this thesis is a re-conceptualisation of science education.

1.2 The Main Ideas

The view that there are no new ideas in the world is not difficult to accept in the field of human affairs. Scientific knowledge advanced spectacularly once deference to Aristotle and other philosophers of old was replaced by critical examination of the behaviour of the world. Yet many of the current questions about important aspects of human existance are just those that have been asked for centuries. Scientific theories about the nature of matter move to deeper and more complex understandings, but different theories about how best to teach seem to be periodically recycled as political and other social climatic factors change. For example, in the early 1980's Peter Fensham launched a science education reform movement based on 'Science for All' (Fensham, 1985). However, this was predated by an English report of 1918 from a committee that was specially appointed to:

> describe the sort of science teaching which is suitable to form an essential part of a liberal education, and to report on the scope and nature of "Science for All" in Public Schools
>
> quoted in Westaway (1929), p90.

One of the aims of such a science course was 'humanizing the work as much as possible by using daily-life phenomena, practical applications, machines, agricultural processes, &c.', and within the aims, 'complete freedom should be left to the teacher in accordance with his (sic) interest and opportunities'. This latter idea of freedom for the teacher also features in this thesis.

However, within these limitations on originality, this thesis does bring some ideas newly to bear on science education. First, the justification for teaching of science is given in terms of social goals. Science Literacy and Science-Technology-Society movements promote science for social decision-making and for coping with a technological world, but my justification for science teaching goes beyond these. I see science education acting as an agent for social change by teaching skills and attitudes that will help citizens promote a more democratic society.

The second contribution of this thesis is the call for science educators to consciously reject postmodernist views of science, and to project a view of science as 'the search for truth about our material universe'. They must do this without returning to earlier, positivist views, and this will require the adoption of a moderate realism (I will explain in Chapter 8 why I believe that the weaker form of realism, semantic realism, is inadequate). Within the modest realist tradition, teachers should develop in students scientific thinking and a science-compatible world view. With such a view citizens would not accept social conditions as a given, nor would they mistakenly expect social problems to be absorbed and solved as part of science. Rather, citizens with a science-compatible world view would be capable of taking scientific skills out into the world and using them to openly scrutinise their social world.

The third contribution of this thesis lies in drawing a distinction between holding scientific ideas at various levels of sophistication, and holding manifestly unscientific and incorrect ideas. For teachers whose own science knowledge is at a rudimentary level, such a distinction should relieve the concern about children being right or wrong, and at the same time prevent teachers from falling into an 'anything goes' type of relativism.

As a fourth contribution, the notion of a 'dilemma' is introduced in its original Marxian sense of a natural dialectical phenomenon. Applied to the classroom situation, the idea of a dilemma means that teachers should not see conflicting demands as an aberration requiring resolution but rather as a continuing inevitability to be dealt with on a case by case basis.

This need for flexibility in classroom decision-making leads to an original model of teaching as the fifth contribution. This model specifies outcomes compatible with our rationale for science education, but also gives teachers the autonomy to apply their 'local knowledge'. As a consequence of this need for local knowledge, any research effort, or curriculum advice to teachers, will need to avoid being prescriptive. In Chapter 10, I explore briefly an appropriate research model, and I offer a critical evaluation of our current science curriculum document (Ministry of Education, 1993).

The main arguments establishing the rationale and goals for science education appear in Longbottom & Butler (1999).

1.3 The Raw Materials of Science Education

The primary concern of this thesis is with establishing a rationale for teaching science. However, the larger goal of improving primary school practice makes it prudent to examine some of the factors influencing classroom conditions. At Christchurch College of Education, a typical 100-level, primary-science, pre-service class has 36 students, mainly female, with an average age in the mid twenties. The ages range from mid forties to late teens and most students have had some post-school experience. Few, if any, will have tertiary science qualifications, and three or four might have taken chemistry or physics at senior high school (these numbers might rise to double figures if biology is included). Some students will be unable to remember whether they did science at form five or not, and even those who studied a science at senior level are unlikely to claim a high level of understanding. Despite this seemingly depressing lack of qualifications, the majority of students express both a willingness to have a go at teaching science and a determination to do better for their pupils than was done for them.

For teachers in schools, science can still be one of the neglected curriculum areas. We routinely ask students about science lessons they have seen on practicum and, at most, two or three report having observed their associate teaching science. Frequently, there is no-one who saw science being taught. Anecdotal evidence would suggest that, where science is taught, topics tend to be those that are covered by library research, discusions on the mat or other non-experimental activities. None of this is surprising given the curriculum strengths of teachers and the deluge of curriculum changes faced by teachers over the last five or so years. Most secondary teachers are being asked to deal with perhaps two new curricula, their primary school colleagues have six new curricula (English, Mathematics, Science, Social Studies, Technology and Health) with more to come.

The openness of the present science curriculum presents opportunities for teachers but also produces problems, especially for those who do not have a subject strength in this area. Two support publications, 'Developing Science Programmes' and 'Investigating in Science' were produced shortly after the release of the curriculum document (Ministry of Education, 1995a, 1995b). However, conversations with primary teachers suggest that they have not found these resources particularly useful. Perhaps, in part, because the books attempt too much by covering from junior primary to senior high school. Commercial support materials, for example the Sunshine Series (Biddulf & Biddulf, 1992) and the Science Alive packs (Hanifin & Smythe, 1995) are well presented. Unfortunately, some teachers are easily enticed away from a practical/experimental base for their science teaching by the excellence of the print material (although activity cards are part of the Science Alive packs). In contrast, the three most recent Ministry publications, the Material World' and 'Making Better Sense of the Physical World' and 'Making Better

Sense of Planet Earth and Beyond' (Ministry of Education, 1998, 1999a, 1999b) are aimed at primary teachers and do seem to contain the level of support needed in content knowledge and in practical investigations. This is important progress because any reform needs to take into account the reality that primary science will be taught by teachers without expert knowledge.

Direct help for teachers comes from the Advisory Services across the country and, in addition, potentially valuable support comes in the form of Ministry-contract, teacher development programmes. From my own experience, and from comments of those involved in other programmes as both providers and participants, there is a level of frustration at the limited amount of follow-up with resulting reduction in long term effectiveness. Even amongst the positive teacher evaluations reported by Gilmore (1994), the need for on-going support was emphasised. Bell (1993) identifies a number of personal factors essential for effective teacher change and, although Matthews (1995) objects to some of these as peripheral to science teaching, we should reflect that education is about people. The content of science comes from the investigation of an objective universe but the process of science, and certainly the teaching of science, involves the interactions of human beings.

> Kímai ki ahau
> He aha te mea nui o te Ao.
> Máku e ki atu,
> he tangata, he tangata, he tangata.
> [It is asked of me,
> what is the thing that is of greatest importance in the world.
> I shall respond,
> It is people, it is people, it is people.]

In the final analysis it is people who are are the key to the process of education and it is people who are the target of the outcomes of education. What also is true is that for the process of rational change we do need people, but people who are informed, people with a purpose, people who are enlightened.

In his book 'The Demon Haunted World' (Sagan, 1996) Carl Sagan gently explodes many of today's myths and legends - alien abduction and healing crystals for example - that seem to be so eagerly embraced by the public. Clearly a more rational population would result if we could eliminate such non-science. However, in the introduction, Sagan tells the story of how he disillusioned a taxi driver about many pseudo-scientific beliefs, and of how he later felt saddened about this because the driver had held these beliefs 'not just as some errant doctrine but a precious facet of his inner life'. Equally clearly then, the simple elimination of a person's beliefs can be detrimental. Science educators need to replace pseudo-scientific beliefs by something creative, something imaginative, something to intrigue the non-specialist. The science of scientists can defend us against Sagan's demon haunted world, it can be a candle in the dark, but why stop at the defensive? Science educators must help produce a rational and critically-minded population by building a belief in the rational rather than simply disabusing people of the irrational. Such an empowered population could then enhance the level of democracy and raise the quality of human existence to the point where it becomes possible to eliminate the demons altogether.

CHAPTER 2 A RATIONALE FOR SCIENCE TEACHING

In this thesis I raise three major questions:

Why should we teach science?

What should we teach in science?

How should we teach science?

If there is to be successful reform of science education, then there needs to be clear answers to these questions, and this has not always been the case in previous reforms. The answers to what and to how we should teach are strongly dependent on the reasons we have for teaching science.

2.1 A Question of Why Teach Science

Before leading into the main argument, I need to consider briefly other critiques of science education. Calls for reform are not new. While science courses have long been included in the general education of most children, the effectiveness of traditional courses has come under increasing criticism over the last couple of decades. Demands have been made for courses that would more appropriately fill the role of 'Science for All', (Fensham, 1985) and there have been a plethora of reviews and reform proposals. Reforms include demands that the content of science courses should be made more interesting and relevant to children's lives, or that ways of teaching science should be more sensitive to the way children learn, to the children's gender, or to their cultural background. Such reforms do not generally address the deeper question that we raise, and I will show (in Chapter 5) that some are in danger of encouraging anti-scientific views.

Other proposals, based on the science-technology-society relationship (STS) and on notions of scientific literacy, structure science education around the empowerment of citizens to contribute to decision-making on scientific matters that affect their lives (American Association for the Advancement of Science, 1989). Reforms of this type have admirable but over-ambitious goals that ask too much of science and science education (Shamos, 1988; Millar, 1996). For example, if we broaden the goals of science education to include an understanding of 'economic, religious, political and scientific issues' (Ramsey, 1993), or if we entertain the notion that if science is enthusiastically pursued we will be able to solve all problems (American Association for the Advancement of

Science, 1989), then we set unattainable goals. By setting expectations that will be unfulfilled, we risk public disenchantment with science and with science education, and we open the way for the acceptance of irrational and unscientific notions. So, why should we teach science?

"What do I teach in my science lesson today and how should I teach it?" is a question asked regularly by all science teachers, even if only of themselves as they do their lesson planning. However, behind the question of whether a class should do mirrors or magnets lies the more fundamental issue of why we teach science in the first place. To ask "why choose this or that topic?" is to ask what is the educational point of including a particular topic in a teaching programme. This in turn relates directly to the deeper question asked by Millar (1996); '*why* [do we] want to teach science to all our young people'? [Italics in the original.] Such a question is not often articulated by teachers and only spasmodically are answers to the question attempted by curriculum writers and science education researchers.

Until the question of why teach science is answered, at least partially, we cannot help teachers make decisions about which science to teach and how it should be taught, nor can we help them defend their decisions against criticism from those who are anti-science. In answering the fundamental question of why we should teach science I have been led to consider the place of science education within general education, and the place of general education within society. I assume that one of the roles of compulsory, universal education is to function as an agent for socialisation and that, in a rational society, socialisation involves not only maintaining social institutions but also involves trying to ensure that institutions work to improve the lot of ordinary people. Thus a major goal of education is, or should be, to improve the quality of human existence. My further assumption is that an essential factor in the improvement of society as a whole is the promotion of rational ways in which citizens can influence the conduct and direction of human affairs. Democracy currently provides the best mechanism for promoting rational change in society and for this reason I want to link education in general, and science education in particular, to the democratic project. With this linkage, a primary justification for teaching science to all children lies in science education making a significant contribution to the advancement of a more truly democratic society. In previous times, the goals for teaching science have sometimes included implicit social goals, but explicit goals have more often been concerned with the narrower outcome of learning science for its own sake.

2.2 The Changing Goals for Science Education

I want to argue that reasons for teaching science have often been confused with questions of what topics should be taught and what methods should be used to teach them. Of course, content and pedagogy of science lessons are not unrelated to the outcomes produced but, by themselves, content and pedagogy do not constitute reasons for teaching science. There are at least two reasons why this situation might have arisen. First, curriculum writers are often faced with a pragmatic task of producing something that can be used by teachers who are themselves lacking in science training and who are working in situations not conducive to practical work where there is a lack of equipment. Secondly, there is often a fundamental failure of curriculum writers to deal seriously with the nature of science, and there is the generally unacknowledged influence of various 'stake holders'.

From the early in the history of general education, there has been conflict over what should constitute science education. Spencer (1859) saw science of 'greater worth' than other curriculum areas because it appealed to reason, and it developed memory, judgment and moral discipline. What he and others envisaged was a very practically based science education that would be useful in economic life of society. Others, including professional scientists, were opposed to this notion of 'everyday science' because, they argued, such an approach debased science. They proposed that liberal education should include the study of pure, abstract science. In fact, a 'Science of Common Things' had been operating very successfully since the 1840s (Hodson and Prophet, 1986). This early curriculum included applied science such as mechanics and agricultural chemistry, and as such provided a context familiar to children of the labouring classes. The overt goals of the programme were the intellectual development of children, the acquisition of scientific knowledge and the provision of experiences for the exercise of reason, speculation and imagination. The underlying goal was to improve the moral and religious condition of children of the poor by improving their self-confidence and integrity of thought. The programme was designed so that the restricted linguistic experiences of so many elementary school children was no longer an insuperable obstacle to the growth of rationality. Critics were first to attest the success of the programme. Wrottesley (1860) visited a pauper school where he asked the class for an explanation of a pump, and he reported:

> ...a poor boy hobbled forth to give a reply; he was lame and hump-backed, and his wan emaciated face told only too clearly the tale of poverty and its consequences, unwholesome and scanty diet in early years; but he gave forthwith so lucid and intelligent a reply to the question put to him that there arose a feeling of admiration for the child's talents combined with a sense of shame that more information should be found in some of the lowest classes on matters of general interest than in those far above them in the world by station.' Quoted in Hodson and Prophet (1986) p173

Although the reasons are disputed, the fact of the matter is that science was removed from the elementary school curriculum in 1862. It was reinstated some twenty years later, but in the pure and abstract form favoured by scientists and the upper strata of society. Hodson and Prophet argue that the changes occurred not because pure science was a more effective vehicle for educating children nor because it was a more worthy area of endeavour. They argue instead that the changes had more to do with social control and the desire of the ruling class to capture the advantages that science education offered in this new age.

Interestingly, the stated goals for the new, pure science remained much the same - the 1882 Code stated that elementary science lessons were to be 'adapted to cultivate habits of exact observation, statement and reason'. However, Uzzell says of the science syllabus for standards I to III that it 'completely lacked purpose and system' (Uzzell, 1986). What had altered was the accessibility and the motivation for both children and teachers. The lessons were to be similar to the 'Object-Lessons' of the New Zealand Primary schools in the same era. In such lessons children were to observe a common object closely, or in a new light, or to compare two similar objects; the stated aim of such an exercise was to 'extend children's powers of observation and to extend their reasoning powers'. Unfortunately, a survey of reports in New Zealand Gazettes of the time shows that inspectors' universal complaint was of the lack of observation and reasoning, and that teachers took lessons from books, or simply lectured on unusual objects; "lecturing on the wonderful" as one inspector put it (Longbottom, 1979). It was during this time that Armstrong, in England, argued strongly for a practical approach to science, and the science education debate shifted from the reasons for teaching science to the methods for teaching science. It is understandable why the problem of poor teaching assumed priority but it is unfortunate that this diverted attention from the reasons for teaching science. It was still assumed, if not explicitly stated in syllabi, that the reasons for teaching science were to do with gaining 'scientific habits of mind', seeing 'interrelationships among facts', and drawing 'appropriate conclusions from evidence'. Unfortunately, these aims tended to lose sight of 'the abilities of many of the children' and 'the often inadequate facilities in the schools' (Uzzell, 1986). Perhaps one might guess that the knowledge level of the teachers would also be a salient factor. However, even as teachers' knowledge of science improved, as schools received equipment and as students participated in practical work, the major problem, the abstract nature of the curriculum, denied the majority of children any real understanding of science and any real chance of gaining the ability to think scientifically.

Bybee and Ben-Zvi (1998) assert that;

> 'In primary and secondary schools, the main reason for teaching science today is the same as it has been in the past - to give students an understanding of the natural world and the abilities to reason and think critically *as they explain their world.*' p 491 [Italics added]

I have highlighted the last part of the sentence because I believe that it represents a significant shift in recent times from the reason for teaching science in the 1850s. In these earlier times science was clearly a *vehicle* for developing rationality, the underlying goal related to broader moral and religious dimensions; this is in contrast to the implied narrowness of today's goals where reason and critical thinking are restricted to 'explaining their world'. Some confirmation of the restriction on the application of reason to a narrow context is given just two pages earlier where Bybee and Ben-Zvi (1998) state that;

> 'Throughout the history of science education, three major goals for students have been (1) to acquire scientific knowledge, (2) to learn the procedures or methodologies of science and (3) to understand the applications of science, especially the relationship between science and society.' p 489

Later in their paper, Bybee and Ben-Zvi conclude that if curriculum developers can integrate the above three goals then;

> '...students lives will be enriched, the levels of scientific literacy will be heightened, and the sympathy towards science as a way of knowing will be enlarged. More students will pursue careers in science and engineering, and we should continue to develop the understanding and skills required to solve our most vexing problems.' p492.

Such views underpin major reform programmes such as Project 2061 where, despite the liberal rhetoric of scientific literacy, the major assumption is that more and better science can solve all problems. These views are descended directly from those of the professional scientists who helped ensure the demise of the 'Science of Common Things' and, in so doing, very conveniently assisted the ruling class to maintain its privileges. These views are also just those which will increase public disenchantment with science and help to legitimate post-modern attacks on science. (See Chapter 5)

Roberts (1988) asked the question 'What counts as science education?', and concluded that it has 'a socially determined answer rather than one theoretically or academically determined'. He identifies seven emphases that a curriculum might have (for example, science for everyday coping, and science as correct explanation) and for each of these emphases he examines what the implicit view is of Science, of the Learner, of the Teacher and of Societal Needs. While this provides a useful analysis, a decade later Hodson (1998) says of Roberts' initial question, 'it is still a pretty good question, though we may only be a little nearer to a satisfactory answer'. Hodson goes on to paint a broad picture of science education as 'enculturation' and of the need to avoid both the 'exclusion' of some pupils and the 'assimilation' of others. He covers important and easily ignored affective aspects of teaching/learning, the issues of motivation and independence of pupils, and pedagogical concerns with practical work and authentic contexts. Hodson defines the goals for science education as the establishment of 'critical scientific literacy' which is a broader notion than the scientific literacy of Bybee and Ben-Zvi (1998). For example, Hodson's critical scientific literacy lays emphasis on the transitions between everyday ways of communicating and scientific ways of talking and arguing, and on social decision making and social action. The notions of social decision making and social action present a classic problem of how to resolve issues where the concerns of lay-people clash with the knowledge of experts, this issue will be addressed in section 5.4

Wallace and Louden (1998) identify three recent phases of change characterised by the emphasis placed on i) discipline knowledge (where curricula are designed by curriculum experts), ii) relevant knowledge (where concern is expressed for social and environmental issues) and iii) imperfect knowledge (where attention was paid to children's prior understandings). It is easy to identify where the Nuffield schemes, STS courses and constructivist teaching programmes would fit in this analysis. For future reforms, Wallace and Louden recommend four guiding considerations:

> '1: Whose understanding of science will be operationalised in the curriculum?
>
> 2: How does the curriculum relate to the understandings of school and science held by students?
>
> 3: What do teachers already know about teaching and learning in science?
>
> 4: What are the range of contexts in which the curriculum will be implemented?' Wallace and Louden (1998), p 480-481

While these are clearly important considerations, a notable absentee is any consideration of why we might be teaching science in the first place!

What of our own curricula? Prior to the present curriculum the primary school level was served by two official curricula; 'Science for Forms I and II' (Department of Education, 1967) covered Year 7 and 8, and 'Science, Primary: to Standard Four' (Department of Education 1985) covered Year 1 to 6. The Form I and II document was heavily influenced by the structure of the subject matter, and in this sense it mirrored junior secondary school curricula (an integrated Form I to IV curriculum was produced in 1975 but remained in draft status). Justification for structuring of material into conceptual themes is related to the assertion that 'science teaching in the past had been concerned too much with the teaching and memorisation of *unrelated* facts'. [Science for Forms I and II, p 4 , italics in the original]. Although there is a succinct description of the teaching methods to be used, the level of scientific expertise required far exceeded that of most teachers, and the concepts simply became new 'facts' to be memorised. Part of the reason for developing the 1975 Draft I to IV curriculum was the expressed concern over the very abstract nature of the concepts and the resulting lack of enjoyment by both teachers and pupils of the 1967 Form I and II curriculum.

The Primary: to Standard Four document had a much more 'user friendly' look to both the presentation and the content. A series of colourful and well illustrated four and eight page booklets set out such things as the aims, programme planning and the role of the teacher. While the amount of written material was not burdensome for busy teachers, there was an attempt to present a balance view. For example, science is described in ways similar to that of the current curriculum as 'both shaped by, and shaping our culture'. However, unlike the current curriculum, it is also clearly stated that 'Science as a discipline has a distinct structure' and that the primary curriculum 'introduces children into the intellectual processes by which knowledge is gained and incorporated into this structure'.

However, the previous curricula and the current one all fail to seriously address the question of why we should teach science in the first place. The 1993 Science curriculum gives twelve goals for teaching science (page 9). Of these, three are standard fare about developing the knowledge of science and the skills and attitudes for scientific investigation, four promote a loose, constructivist view of science as an everyday activity, constructed by people and evolving, two are fairly standard STS goals about making decisions and two refer to the needs of the scientific community and to student career needs. Bar one possible exception, there is no reference to developing reason or rational thought, and there is no reference to anything not directly related to science (either as a focus of study or as an influence on our lives). This one exception, the eighth in the list, gives a goal of science education as;

> 'assisting students to use scientific knowledge and skills to make decisions about the usefulness and worth of ideas.' Ministry of Education (1993) p9.

Even then, in order to interpreted this goal as having any wider application we must assume that the word 'scientific' was deliberately left off before 'ideas'. In terms of the context of the rest of the page, a more probable reading is, I suggest, that 'ideas' was intended to mean 'ideas as scientific ideas'

In fact, the major problem with the curriculum lies in what it does not say. Commissioned by the Education Forum (New Zealand Business Round Table), Kelly (1995) provides a more measured critique than Matthews (1995). One of Kelly's conclusions is that 'the openness of the curricula to varying individual needs' and 'the broad approach to the purpose of education' are 'superficially appealing' but that 'tensions and other difficulties remain unaddressed or, indeed, unidentified'. With such a curriculum, Kelly points out, schools and teachers are left 'to carefully pick and choose their way through the myriad of possibilities'. Such freedom would be a very positive feature if there were clear goals or guiding principles, but it is on just such matters that the curriculum is silent. There is no mention of the nature of science, there are only inferences about the nature of the learner or the processes of teaching, and the aims that are given are jumbled with little focus or coherence. Without this support, the provision of 'choices' simply abdicates responsibility and abandons teachers.

Furthermore, Matthews makes a telling point that must be taken into account whenever we deal with open ended curricula:

> This seemingly progressive idea of tailoring education to student differences or interests is frequently a mask for schools' reproduction of social inequalities ... Schools that adopt progressive pedagogy and minimalist curricula, compound the educational disadvantage of deprived homes.' Matthews (1995), p 162

If this is true, then it would scarcely help to meet the key goal I would like to set for science education, that of helping extend democratic society!

At the end of their paper on curriculum reform, Wallace and Louden (1998) demonstrate tentative optimism that a way forward will be found if we can understand and respect the complex issues involved. They say that the key message of the last 40 years is that 'curriculum change is a complex mixture of the facts of the change process and the values that underpin change' (p 482). I would rather say that the key message of the last 40 years is that little progress will be obtained until we attend to the confusion over, or the neglect of, the reasons for teaching science. One of the reasons for the confusion and neglect has been the dispute over what constitutes science itself.

CHAPTER 3 THE NATURE OF SCIENCE

> *'I would suggest that we might begin...by prohibiting the use of the term "scientific"...for a trial period of say, 10 years.'*
> Polanyi (1957), p 484.

> *'Science, rather than being automatically self correcting, is currently the greatest single source of human error, precisely because it is perceived as the source of certainty and truth.'*
> Rogers (1968), p 189.

> *'The University is plagued as much as any other institution by superstition, prejudice and dogma. The healthiest antidote to such social disease has been science and scientific ways of thinking and working...'*
> Kerlinger (1977), p 8

> *It has been humbling for scientists to come to recognise ... that science is in a sense a cultural artifact. A different society, with a different "cultural hypnosis" ... would have created a different science.* Harman (1988), p 132

These first four quotes were collected, almost for amusement, to show how easy is is to find apparently conflicting views of science. In part, the contradictions apparent in the views expressed above lie in the different meanings that the authors have for 'science'. In this first section I will make explicit the position that I take on the nature of science and later I will relate this to a rationale for teaching science.

The next quote raises the important relationship between truth and teaching, yet another area where we may find conflict and confusion. In section 8.1, I will defend the following view expressed by Bonnett, although I will want to clarify the meaning of 'transcendent'.

> *The fundamental relationship between thinking, understanding and truth can be left out neither of an account of good thinking, nor of how to teach it. ... [Good thinking] rests in a sense of truth which, far from being essentially 'constructed' by us, is transcendent.*
> Bonnett (1995), p 307

3.1 The Development of Modern Science

First, let us look at science. What is science? One view is that science, proper science, arose in Western Europe around the middle of the second millennium. This is not a universally popular view, and it is a view that is likely to lead to charges of ethnocentrism, sexism, scientism, cultural oppression and other heinous crimes. However, this is a risk worth taking because I want to promote the teaching of science for reasons that relate to the social goal of building a better society - not a more scientific society - in fact a society where ethnocentrism, sexism, scientism, cultural oppression would be unlikely to exist. What I will do in the next sections is to outline the development of modern science, and outline the emerging disputes about the nature of scientific methods and status of the knowledge that these methods generated. I will then argue that modern science is a qualitatively different activity to the knowledge generating processes of other times and other cultures. My aim is not to settle long standing philosophical arguments but to set out a position from which I can develop a rationale for teaching science.

It is important to distinguish between the claim that modern science first appeared in 16th century Europe and the claim that modern science was a Western European invention. Any human advance has a history. No human advance has sprung fully formed from a particular culture, instead, each advance has some debt to previous times and previous cultures. Important foundations for modern science were laid down in Greece some two thousand years before the spectacular (some would say frightening) development of scientific knowledge was triggered by Galileo, Newton and their contemporaries. Plato defined and categorised nature by seeking the essence of things, Thales developed formal ways of thinking about some of the obvious truths in mathematics, Aristotle systematised knowledge about numerous aspects of the natural world and Democritus, in suggesting that matter was ultimately discontinuous, provided an hypothesis that was to bear fruit two millennia later. Greek society contained ingredients essential to the development of science; a society in which some members were freed from toil to think, and a body of scholars with an appreciation of academic endeavour. Two key metaphysical beliefs were also present. The first belief was in self authorship, or individual responsibility, (Socrates idea of 'know yourself') which enabled people to distinguish between 'accepted by others' and 'literal truth'. The second belief was in the concept of 'nature' - that the world was a coherent system and that this made it worthwhile for people to commit intellectual effort to trying to understand the world

Not unlike some disputes in modern philosophy, Greek endeavours were split into opposing philosophical camps. Some believed that knowledge was to be found through Platonic idealism, or rationalism, in which the primary task was to decide on how facts were to be organised and only then to go out to seek the facts. Others believed that knowledge was to be gained through Aristotelian empiricism where people allowed observations to determine theories. It is important to emphasise that 'empirical conditioning' meant that idealism did not lead Greek 'science' to be unrelated to reality. The ideas of order and predictability did not simply spring unbidden to mind, they developed in people because there is a degree of order and predictability to the world. Equally, it must be said that empiricism did not lead to knowledge derived purely from observation; it has been recognised by Quine and others that all observations are theory dependent. However, despite these similarities with disputes over modern science, the activities of the Greeks differed in significant ways from the activity of modern scientists. Greek 'science' was a contemplative activity and people were not motivated by the idea of generating new knowledge. Crucially, Greek science was not based on experimentation; knowledge tended not to be put to the test, and this limited the potential for intellectual development.

While the Greeks may not have 'experimented' in the modern sense, neither were they simply passive occupants of the world and this gives one further similarity with the beginnings of modern science. The Greeks inherited a rich store of human technical knowledge accumulated through past human interactions with the world. There was knowledge about fire, about domesticated animals, about crops and irrigation, about medicines and metals - the Greeks lived in 'unnatural times' just as we do now and, even if they did not 'interrogate' nature in the manner of modern science, the Greeks knowledge of the world was, like ours is today, derived from the way the world behaves.

The Roman society which eventually eclipsed the Greek civilisation and held sway over much of Europe for several centuries had an interest in technical knowledge concerning engineering and military and civil organisation, a pragmatic rather than intellectual interest. Tradition and survival rather than science was the feature of even later centuries, the Dark Ages, in feudal Europe. However, changes did occur, there was a slow development of technology and an accumulation of investigative procedures and knowledge arising, for example, from the practice of alchemy. By the 16th century, religion had weakened the belief in magical explanations. There was again a flourishing community of intellectuals who accepted that investigating the world was not incompatible with holding religious beliefs. And the economic system freed some people, through personal fortune or through patronage, to devote considerable time to investigations and 'natural philosophy'. Above all there was a new-found belief in human intellectual ability.

Galileo is usually given as one of the first modern scientists because his science was characterised by experimentation. He designed experiments and made use of direct observation, but he also extended knowledge by means of thought-experiments, by the use of mathematical reasoning, and through his ability to idealise from the rather messy real world. The science of Galileo, Newton and of others who followed, was firmly rooted in the ways the world behaved, but the mind played a large part in interpreting what was seen. The key accomplishment of the early scientists was the weaving of Platonic rationalism and Aristotelian empiricism into a single experimental tradition, and accompanying achievements were the further development of mathematical reasoning and the extensive use of measurement and numerical data.

Following in the footsteps of Galileo and Newton, a raft of experimental scientists explored seemingly every aspect of the natural world. For example, Anton Lavoisier, William Hershel, Michael Faraday and Louis Pasteur all helped, in the best experimental tradition, to shape an increasingly integrated and evermore successful picture of the world. There were national differences in science. In England the experimental tradition was promoted enthusiastically by the Royal Society whose members included Boyle, Hooke, Faraday, Davey and most other famous names in English science. Not all scientists were convinced of the efficacy of experiments, and the European tradition favoured more mathematical approaches. Both Hobbes and Spinoza complained about the new scientific method, not so much because they doubted the usefulness of experiments but more on the grounds that experimental evidence was not accessible for others to critique in the same way that a paper of mathematical theorising was. However, as the culture of experiments spread there was an increase in the number of skilled experimenters who could reproduce experiments and check the results, and the experimental method became mainstream scientific practice. As Chalmers (1999) commented on the Hobbes-Boyle dispute 'Boyle lost the theoretical argument in the domain of philosophy but won the practical argument in the domain of experimental science' (p328).

Disputes such as that between Hobbes and Boyle tended to be about the relative weights that should be accorded to experimental work and mathematical theorising, and it was generally agreed that both were a legitimate part of scientific method. Another issue that did come to a head around the time of Newton involves a question that haunts us still today. That question is whether the goal of science was to gather restricted but certain knowledge or whether the goal should be to gain an understanding of the causes of things, albeit at a lower level of certainty. Newton developed four rules which he claimed governed his own method and which included an affirmation of 'deduction from phenomena' (induction) and a steadfast opposition to hypothetical reasoning. From this method Newton's claim was that:

> 'if they are correctly understood, knowledge of both cause and certainty are obtainable' and in this Newton's view was 'distinct from that of Galileo and Harvey, who were willing to sacrifice knowledge of causes in order to achieve certainty, and from that of Bacon and Descartes, who were willing to sacrifice certainty in order to achieve knowledge of causes.'
> Gower (1997) p80.

At this point, I would like to raise two other questions, although I will not attempt to answer them until section 3.3. The first question is; What is it about the human brain that makes humans investigate, think about, and generate knowledge about nature? One response might be to suggest that knowledge production is simply part of being human (just like using fire, domesticating animals and growing crops) but this is not really a satisfactory answer. The second question is: What connection is there between scientists' ability to produce knowledge about nature and children's ability to learn science? This is of particular importance because of the growing interest of science educators in the theory of theories, and in psychological theories of learning. In Chapter 6, I will return to the question of the link between doing science and learning science.

I now return to the question of the relative weight to be given to certainty and meaning. In contrast to the philosophical meaning of absolute truth, Newton had in mind 'practical certainty' as the goal for scientific knowledge and, from this, theories of probable certainty were developed, for example by Bayes (Stigler, 1982), and much later by Keynes (1921). Doubts about the inductive method had been expressed by David Hume in the eighteenth century, and these doubts continue to surface. The problem is that while inductive arguments seem to give a good practical way of obtaining information about the world, induction cannot lead to truth or logical certainty as deductive arguments do. Thus what seems to be an eminently rational way of obtaining scientific knowledge is not a logical way of proceeding. In logical terms, to prove the principle of induction true you would have to produce a deductive argument, and this would have to assume that the principle of induction was true - simply put, one cannot gain evidence that the inductive principle is true, nor can we prove it false. In the nineteenth century, Charles Sanders Pierce attempted to rescue inductive reasoning through a modification he called abduction, and this appears in modern forms as 'inference to the best explanation' and 'retroductive-hypothetico-inferentialism'.

Bertrand Russell concluded that induction was essential for the operation and justification of science, and he proposed that induction was a logical principle by virtue of what reason tells us about the method - that is, the principle of induction is true a priori. The implications of this are great because this cuts across the long held belief of science: the belief that our knowledge of the world is provided by the world through empirical evidence, rather than being provided by some a priori knowledge independently of our experience of the world. Russell was prepared to sacrifice strict empirical principles in order to save induction, but many were not. Mach, Reichenbach, Carnap and many others remained faithful to the empiricist principle that knowledge comes to us through our senses. An extreme form of empiricism shaped the beliefs of the logical positivists whose 'verification principle' allowed only two classes of meaningful statements; analytic (true by definition) and synthetic (empirically verifiable). However, these beliefs fall foul of their own rules for we can ask 'To which of the two classes does the verification principle itself belong?'. It is not simply a definition, nor is it empirically verifiable; it is a stipulative definition which carries a metaphysical belief. Science, it seems, could not be easily rescued from a logical quagmire.

Popper (1980) recognised the weakness in the logical positivists case, pointing out that 'positivists, in their anxiety to annihilate metaphysics, annihilate natural science along with it'. Popper was concerned to find criteria that would distinguish science from pseudo-science and concluded that induction was a major impediment to this. Writing of Max Born's notion of 'valid induction' he says that it was

> 'meant to serve as a criterion of demarcation between science and pseudo-science. But it is obvious that this rule or craft "valid induction" is not even

metaphysical: it simply does nor exist. No rule can ever guarantee that a generalisation inferred from true observations, however often repeated, is true' (Popper 1980, p27)

And for how science proceeds Popper writes,

> 'How do we jump from an observation statement to a *good* theory? ... by jumping first to *any* theory and then testing it, to find whether it is good or not; i.e. by repeatedly applying the critical method, eliminating many bad theories, and inventing many new ones. Not everyone is able to do this; but there is no other way.' (Popper 1980, p29)

Popper's dismissal of induction did not impress Reichenbach who wrote in a review of Popper's book *Logik der Forschung* ,

> 'the theses presented in Popper's book... appear to be completely untenable'; and 'I am ... unable to understand why Popper believes his investigation to constitute even the smallest step forward in resolving the problem of induction'. (Gower 1997, p209)

Of this dispute between Popper and Reichenbach, Gower (1997) writes:

> 'Both Reichenbach and Popper ... were committed to the exposure of appearances as deceptive. For Reichenbach the task was to show that the apparent irrationality of induction was illusory; for Popper the task was to show that the apparent indispensability of induction was illusory. In both cases the illusions, if that is what they are, have stubbornly resisted their attempts to expel them.' p210

Popper's actions of separating the contexts of verification and discovery, and of assigning the latter to some sort of trial and error process seems to have cut us off from the most interesting and creative aspects of science. In terms of the question about the 'truth' attainable in science, Popper was right to try to distinguish science from pseudo-science but wrong to identify science just with verification. Science encompasses the whole careful, painstaking community effort of scientists that is bound by a code of ethical conduct. Science is not a strictly logical process and there is no predetermined trajectory of discoveries that science must follow, but this does not mean that science is not a rational enterprise. The problem with the efforts of both Reichenbach and Popper to show that some components of science are logical is that it leaves it open for others to claim the enterprise as a whole is irrational or, at best, a-rational - a matter I will return to in section 3.3. In the next section I will outline some of the more recent views of science.

3.2 Naturalistic Views of Science

As science became more successful in building an understanding of nature, and particularly as science became an increasingly powerful force in all aspects of people's lives, two trends emerged in studies about science. First, there was increasing philosophical interest in explaining how science was able to produce reliable knowledge. Second, and most recently, some sociologists have shown interest in studying what scientists actually do. This has led in some cases to attacks on the status of science and on the status of scientific knowledge.

Kuhn (1962) was the first of many to derive a theory from the study of case histories in science and his now famous notion of paradigm shift was first published in 'The Structure of Scientific Revolutions'. Kuhn's notion of theory change as some kind of dislocation has been followed by Lakatos' softer view of science as a Research Programme with a central core of beliefs and protective belt of auxiliary theories and by Laudan's even more open view of a triadic network of ontological, epistemological and methodological beliefs that are not constrained to change simultaneously. I will only consider Kuhn here because his seems to have been the most influential view, particularly within science education.

Serious and continuing charges of relativism are levelled against Kuhn, and he has steadfastly denied them. Kuhn (1980) writes that he has been 'very much surprised' that he has been held to have claimed that:

> 'Members of a scientific community can ... believe anything they please if only they will first decide what they agree about and then enforce it both on their colleagues and on nature. The factors which determine what they do choose to believe are fundamentally irrational, matters of accident and personal taste. Neither logic nor observation nor good reason is implicated in theory choice. Whatever scientific truth may be, it is through-and-through relativistic.' p 207

Of such 'misinterpretations' Kuhn remarks that they are made 'only by philosophers'. If this were so then there would be no problem, but while scientists are likely to remain immune from such influences, there is strong evidence that science education has been greatly influenced by Kuhn's ideas (Loving & Cobern, 1999). Some, particularly those interested in multicultural science, have accepted the relativistic ideas (for example, Ogawa, 1995). The problem is that Kuhn, like Popper, is silent on how theories are generated. Even of reasons for theory choice, Kuhn says that, while not denying that there are good reasons for choice, 'such reasons constitute values ... rather than rules', and that values such as 'simplicity, scope, fruitfulness and even accuracy' can be judged quite differently (Kuhn, 1980, p 209). Whatever Kuhn may have intended, he offers so little as an alternative that he should not have been surprised that he has been read as a relativist.

Ohlsson (2000) claims that despite appearances the ideas of Kuhn and Popper are very similar, and he poses the question of why Kuhn was more popular. According to Ohlsson, the answer lies in the approach taken - Kuhn adopted a naturalist approach, Popper a normative one. Since Kuhn's work, the naturalist approach has been dominant, either through the broad study of case histories as in the case of Kuhn (1962), Lakatos (1970) and Laudan (1977) or through the intensive study of a particular scientist, for example that of Faraday by Gooding (1990). Ultimately, sociologists have developed views of science by studying scientists at work. These views have often been critical of science, and some have even portrayed science as just another way of explaining the world - one of the more extreme views being that in strong programme (Barnes & Bloor, 1982). Poole (1998) has noted that the denigration of science, and the rejection of rationality in favour of either subjectivism (where truth lies in the mind of the thinker) or relativism (where truth lies in the collective decisions of society), has followed a period of scientific ascendancy and deification. If we are seeking psychological reasons for denigrating science I would add to the list, the increasing complexity of science, its increasing influence on our lives and, indeed, its very success in producing knowledge at an accelerating rate. The problem for those wanting to defend science is that its very success, and its influence across almost all aspects of life, makes it difficult to promote science without attracting the charge of scientism.

Feyerabend, famous for his anarchistic, 'anything goes' view of science, does not actually denigrate science as a whole, but only the current form of science, and particularly science as it is currently taught. In assessing the role of science he writes:

> 'Any ideology that breaks the hold a comprehensive system of thought has on the minds of men contributes to the liberation of man. Any ideology that makes man question inherited beliefs is an aid to enlightenment. ... It follows that seventeenth- and eighteenth-century science indeed was an instrument of liberation and enlightenment. It does

not follow that science is bound to remain such an instrument.' Feyerabend (1980) p 57

His view is that science or any ideology (which he holds science to be) is acceptable when countered by one or more competing ideologies, the danger lies when one ideology becomes dominant. As a tongue-in-cheek example in the field of education he gives 'three cheers to the fundamentalists in California who succeeded in having a dogmatic formulation of the theory of evolution removed from the text books and an account of Genesis included'. I will return to some aspects of science as ideology in section 5.4. In the meantime it is important to recognise the distinction between science as liberating and science as oppressive, and to try to tease out the varying views of science that conflict and overlap in a most confusing way.

Where are the battles over the views of science fought? Loving (1991) has produced a useful categorisation of positions on a two dimensional grid in which the dimensions are Rational versus Ideal and Realist versus Anti-realist. This is a simplification first because views do not exist as nice binary pairs, and second because there are potentially five different aspects to science: Ontological, Epistemological, Methodological, Metaphysical and Explanatory. I say potentially because, for example, many empiricists are likely to deny that there are metaphysical aspects. To give some examples of the complexity of ideas, modern empiricists would include Giere (1988), van Fraassen (1980) and Cartwright (1983). All would claim primacy of observation over a priori theorising, all would hold to the existence of a world 'out there' but only to a semantic view of theories as models that mapped onto the real world. The first three would deny the place of metaphysical beliefs whereas Cartwright (1994) has modified her views to allow a limited metaphysical influence and, further, is not entirely opposed to realism (Clarke, 1999). In terms of methodology, Longino (1990) and Harding (1991) both argue, in a way that echoes Feyerabend, for multiple (subjective) perspectives to operate in science in order to make science as a whole more deeply objective. They cite example of corrections that have occurred as the result of a feminist perspective being brought to science research. Alternatively, Kitcher (1993) sees objectivity occurring through consensus within a community and Giere (1988) takes it to reside within the individual. Even subjectivity and objectivity have an added layer to them as Scriven (1972) distinguishes between qualitive and quantitative aspects of subjectivity and objectivity.

3.3 An Evolutionary View of Modern Science

I will now outline what I believe is a reasonable account of science. It describes and explains the growth and conduct of science and, I will argue later, also provides a good underpinning for science education.

I will not try to model science as a complete system that can be governed by rules and logic: Bronowski (1968) concluded that it was impossible to describe nature in a single, closed, consistent language. Neither do I want to select just pieces of science to defend as logical, as did Popper, for this leaves science as a whole open to attack. I concur with Ziman who argues strongly for the need to considering science as a whole:

> 'By assigning the intellectual aspects of Science to the professional philosophers we make it an arid exercise in logic; by allowing the psychologists to take possession of the personal dimension we overemphasise the mysteries of "creativity" at the expense of rationality and the critical power of well-ordered arguments: if the social aspects are handed over to the sociologists, we get a description of research as an N-person game, with prestige points for stakes and priority claims as trumps. ... Before one can distinguish and discuss separately the philosophical, psychological or sociological dimensions of Science, one must somehow succeeded in characterising it as a whole.' Ziman (1980) p 42

In order to give a broad picture, I will assemble what I consider the essential parts. I take as uncontroversial that science requires a community of enquirers and requires the social conditions specified in section 3.1. Thus we need an economic system that can free some people to think and an academic tradition that values knowledge on more than pragmatic grounds. Furthermore, since experimentation is a key element to modern science, there needs to be a minimum level of technology. In contrast to the empiricists, I suggest that metaphysical beliefs are an essential component of science; specifically, the concept of nature as a coherent system and the notion of self-authorship (the distinction between self and group) are essential prerequisites for science. These conditions seem necessary but hardly sufficient for science to occur. So far we could not answer the question posed in section 3.1: 'What is it about humans that enables them to investigate, think about, and generate knowledge about nature?'

To answer this question I will move cautiously to a speculative, evolutionary explanation. I say cautiously because, while I find this a useful way of thinking about science education, I do not want to tie my argument too tightly to such a speculative model of science. Furthermore, naturalistic approaches can be seen to provide a kind of empirical foundational view that this is how things really are (as we have seen in the conclusions drawn by sociologists of science). However, there has been some interest in genetically selected aspects of brain function (for example, Edelman, 1992, & Plotkin, 1994) and, in the next two paragraphs, I will outline some similar ideas and relate them to the development of science.

Plants have structural features that assist their survival, for example leaves are the site of photosynthesis. Plants often have environmental reactions, for example a tree will drop its leaves in a severe drought. Simple animals have equivalent structures and reactions, and more complex animals have behaviours which appear to involve decision making - a cat crouches instinctively on hearing a noise, but then decides to run or continue on. At a higher level, animals develop more sophisticated strategies on the basis of experience (learning) - an alley cat will ignore some familiar noises that would spook a country cousin. In primates there is evidence for learning being passed from one generation to the next (teaching). In humans, learning is raised to a new level. The ability to seek patterns and infer meaning seems to be a key feature of this newly selected species. Of course, while 'learning' occurs within individuals, a second important feature lies with the communal nature of humans. The development of speech and symbolic representation allowed the pooling and passing on of tribal knowledge, and this elevated our pattern-seeking ability from a feature that enhanced our survival to one that ensured our ascendancy.

In a pre-literate society, social knowledge is passed on, and the world is explained, through the telling and retelling of story and myth. Typically, a pre-literate society will have a language with a small vocabulary, and will use words in a way that results in truth and metaphor not being routinely distinguished. The explanatory myths and metaphors of pre-literate societies are qualitatively different to the understandings produced from modern science. With the advent of written language, vocabulary expanded, there could be more precise communications, words could be given more tightly defined meanings, and it became important to distinguish literal truth from metaphoric use of language. However, even with the favourable conditions present in ancient Greek society, the philosophic and contemplative activities of this era were not scientific in the modern sense. So, what did trigger 'modern science' and the cognitive processing that we know as scientific rationality? One thing is certain, we could not explain the spectacular changes over the last 500 years by evolution - what ever ability we have must have been already present in the earliest societies. What does distinguish modern science from all previous meaning-making is the experimental tradition, the notion of actively interrogating nature. By actively checking the veracity of theoretical claims, and by developing the techniques of investigation, scientists have extended the range of 'observables' to include what were previously 'theoretical entities' (for example, the germ theory of disease and micro-organisms). Our modern scientific ideas about the world are derived by using the same meaning-seeking ability possessed by our distant ancestors. The spectacular acceleration in knowledge generation is because truth-seeking (as opposed to meaning-making) and active experimentation (rather than passively observing) form a positive feedback system of critical reflection on our own thinking, on community knowledge and on the process of science itself. Scientific rationality is enhanced as we gain more understanding of the world, and our ability to think more scientifically enables us to get a better understanding of the world. This is not to claim that previous eras and pre-literate cultures were (or are) irrational; it is just that modern scientific rationality is a qualitatively different way of thinking, a qualitatively different way of using our long existing natural propensity to seek patterns and find meaning.

One result of actively seeking an understanding of the world has been a dramatic shift in the way in which humans view nature and the way in which our harnessing of natural forces has altered the way we live. This is not an entirely new phenomenon; using fire, domesticating animals and building irrigation systems are also associated with social change. The period of modernity is characterised by a qualitatively different way of thinking and a quantitatively different way of living. Humans have always sought meaning but not in the same manner as modern science; technology and change have always been present, but not at the same speed as now. Post-modernists, and others, have legitimate concerns over our effect on the environment and the alienation produced by modern living, and they ask sensible questions about how much knowledge we need and who benefits from it. I suggest that it is impossible to dis-invent science and return to the life of some previous time, that it is increasingly dangerous to carry on as we are, and that one solution is to add scientific reflectivity to the way of thinking of all citizens. I will expand on this in section 8.2

If it is dangerous to carry on as we are, then some changes need to be made. These changes should involve rational solutions, and include science in any future human society - the changes should not be postmodern ones which involve the denigration and devaluing of science and scientific knowledge. However, is our society open to rational change? This is the subject of the next Chapter.

CHAPTER 4 THE NATURE OF SOCIETY

4.1. Democracy and How We Might Achieve It

A truly democratic system would be one in which all citizens express their humanity by making rational choices about their own lives, and where each of them is able to join others in influencing the general direction of society. In our present society, movement towards this ideal is retarded by the economic impotence of many. The rationality of a person's decisions is in question if they live with fear in their homes; if they are forced to watch their family go hungry; or if they exist without thinking, without a vision and without hope for the future. One of capitalism's weaknesses is that in most capitalist societies unemployment is endemic, and this excludes a significant percentage of the population from mainstream society. At best these people subsist on a paternalistic welfare system, at worst they are allowed to eke out a brutalising existence in overcrowded city slums or substandard rural housing. The situation of many elderly people, and those in low paid and casualised jobs, is little better than that of the unemployed. The reality is that behind all the rhetoric of opportunity and choice, there lies the crude fact that in a 'market economy' economic muscle is paramount - put bluntly, if you have no money you have no choice. This is not to imply a determinism, but simply to state that the opportunities and influences of Bill A Smith, company director, living in Remuera, are likely to be significantly greater than those of Bill B Smith, unemployed and renting in Mataura. This situation is in conflict with any enlightened concept of democracy, so why is such a socially destructive situation allowed to continue? The answer lies in the general lack of understanding of the processes and power structures in society. Probing questions are rarely asked, and action almost never taken, even over the grossest social inequities. This reflects an inability of most of the population to ask appropriate questions, and a conscious decision by a small minority not to act.

The concepts of democracy developed within capitalism, and particularly those implied by Hayek and the current exponents of right wing philosophy, are all based on the primacy of the individual, that is on the maxim that what is best for each individual is best for society. Individuals are taken to be motivated solely by self-interest and, in its extreme form, ontological individualism leads to the conclusion that society is an abstraction - *vide* Mrs Thatcher and some of our own right wing ideologues - and can be said not to exist at all. Soltis (1993) describes a model of democracy for twentieth century, amoral, consumer-oriented and acquisitive societies as follows:

> In such nations, be they one-, two-, or multi-party systems, a cadre of professional politicians are the "entrepreneurs" who sell themselves to the voter-consumers for a term of office wherein they, not the citizens, make decisions and maintain an equilibrium in the distribution of political, economic and social goods. The people are then free of political responsibility and go their own way in pursuit of their own interests, material needs and wants while being governed by professionals. Needless to say, in such a democracy, education for citizenship would seem to require only minimum effort. [p151]

Clearly, such a democracy will have very limited potential to promote general human development.

Snook (1995) is even more critical of government under a 'New Right' or 'Libertarian' banner claiming that:

> as the communist regimes have collapsed under the democratic banner, some western democracies including [New Zealand] are in the process of instituting their own form of dictatorship.

Both Soltis and Snook are describing societies that have some of the formal structures of democracy but fail to have the democratic spirit - such a characteristic is not unrepresentative of capitalist societies. However, within educational writings we find a broad and liberal (as opposed to libertarian) view of democracy in which emphasis is placed on community goals and active participation by all members. The democratic ideals of Dewey (1916) are implied in the radical critiques of Bowles and Gintis (1976) and Apple (1985), and extended by writers such as Gutmann (1987) and Levin (1998). If we are to make progress with democracy, it is important that education for democracy, and education about democratic ideals, continue to be a feature of general education.

Education for a democracy places obligations on the school as a community to reflect democratic ideals (Dewey, 1916), and also places restrictions on the style of teaching used (Portelli, 1993). Portelli characterises teaching and learning as 'an intentional and cooperative activity'. He condemns 'hidden curricula' and any resulting covert outcome, even if these outcomes are educationally defensible. He argues that all goals should be made explicit since teaching must involve an element of trust, and trust demands openness. In my view, educators should use all ethical ways possible to demonstrate and develop democracy within capitalism while avoiding the utopianism of Dewey, and the naively confrontational approach of the radical critics.

What we must do is to break away from the image of education for democracy as simply preserving the status quo; such an image is based on the naive view that we have achieved democracy and simply need to protect it. Children need to be taught democratic ideals as part of general education. One possible path to a truly democratic system lies in the linking of the individual with wider society, as expressed in Habermas' theory of communicative action (Peukertruth, 1993). In this it is observed that individual development can only take place within a nurturing society, that is the development of autonomy and independence in a child is necessarily accompanied by a corresponding development of greater mutual interaction in human relationships. If every individual was enabled to consciously live their own life in a way that was linked to the ability of all others to do the same we would make individual freedom and universal solidarity complementary rather than contradictory concepts. In exercising rational decisions about our lives, we would be bound in our actions to ensure that all others can exercise the same rights. Such an ethic could not be satisfied with a merely formalised democracy because, for many people, democracy without the democratic spirit, means that notions such as 'freedom to choose' do not represent real options.

Unfortunately, even if we are successful in teaching democratic ideals, there is no guarantee that having such ideals will enable citizens to promote change. If human society is simply not open to change by conscious action, or if the power structure in a particular society inhibits change, then democratic ideals will remain as ideas in people's heads. The next two sections explore the relationship between individuals and their society and give an analysis of some aspects of advanced capitalist society.

4.2 The Relationship Between Individuals and Society

When analysing social issues it is easy to accord too much responsibility for action to individuals (when in reality they are greatly constrained by their social context) and it is equally easy to use the constraints imposed by social context as an excuse for inaction. The challenge is to steer a path between these two extremes. In this section I develop the view of Bhaskar (1978) which maintains a balance between individual independence and social determinism.

If we ask what distinguishes humans from other animals, the answer can be framed in concrete form. It lies in such things as using language, wearing clothes, printing books, extracting minerals, painting murals, building dams, writing poetry, constructing mathematical models of the atom, and walking on the moon - a mixture of curiosity, creativity, and the knowledge and technical ability to consciously influence both the physical and social environments. We can attribute these characteristically human abilities to neuro-physiological structures - an enlarged cerebral cortex - or to psychological characteristics such as intelligence and rationality. However, individual humans could not have utilised these neurological structures, nor displayed these psychological characteristics, without the physical, emotional and intellectual support provided by a social grouping. What this means is that social organisation is an aspect of the essence of being human, and that our humanity is partly defined by our social relationships. In other words, we have an individual existence but we could not exist independently of society. This indeed is the answer to those who hold to ontological individualism - 'the individual' makes no sense, and the individual could not even exist as a human person without the language and structures devised by social groups.

In Bhaskar's view, society is a web of relationships (for example those within the family or those within the political and economic system) which exists within an objective set of physical and intellectual artifacts (for example, the climate, the roading system, concepts of equity or theories about the structure of the solar system) (Bhaskar, 1978). Each individual is born into a society which provides both the conditions for that person's development, and the framework for their intentional actions. Thus existing society passes influence downwards to its citizens through the process of socialisation (taken very broadly). Since society preexists any particular individual, intentional human action is moulded by society.

However, this does not imply complete social determinism, for society itself does not exist independently of human action. The network of relationships, which is society, is confirmed and made real through the daily actions of individuals. This process of confirmation can be intentional, for example when we take part in elections or obey the instructions of our head of department. Alternatively, we may be unaware of the consequences of our actions, for example, by choosing to attend a science education conference the participants are helping confirm the importance of academic research and also consolidating their own institutional position. There are also times when our actions promote change, for example, by choosing to take a car to work we intentionally, or unintentionally, undermine the public transport system.

Individuals are not of paramount importance and society is more than the sum total of the actions of autonomous individuals. However, neither are humans the predestined products of their historical background and social environment. Providing that we are not lulled into accepting that choice is mediated through market forces, there is a degree of freedom in all aspects of social life. Teachers may not be able to mould children as they please, but teachers are able to present alternatives, to create opportunities and to implant ideas. The education system does provide one avenue for social change.

Thus, the institutions of society are continually being reproduced or, to varying degrees, transformed. The mechanism affecting social institutions is the daily actions of people and this may produce change either intentionally or unintentionally.

It is important that the institutions of society be reproduced, for this gives stability to society. However, a successful society will be one that exhibits change as well as stability. Society has been changed unintentionally as the result of a wide range of actions, the most dramatic changes often being related to the adoption of a new technology such as the spread of the printing press or the harnessing of new energy sources. Change has also been brought about by the conscious actions of a few or the considered actions of citizens as a whole, but rarely are such changes exactly as intended - neither the projects of ambitious kings nor the results of popular uprisings are entirely predictable. All of these change mechanisms have operated in the past and will no doubt continue to do so. However, we wish to promote the democratic development of society, where the considered and collective actions of members of society result in relatively predictable changes serving the interests of all members. To maximise the success of any such mechanism we need to understand the operation of our present society.

4.3. Our Social Structure and the Potential for Change

Human society and history can be bewildering in its complexity. In their everyday lives, human beings generate knowledge, pass on ideas and learn new skills. This activity creates intellectual and physical artifacts that alter the material conditions under which the future is constructed. From this complex and potentially chaotic system, Marx produced a broad synthesis of human history and a small number of powerful generalisations and insights that help us to understand human affairs. In this way Marx's contribution to history and sociology is analagous to Newton's contribution to science and engineering.

Marx traced the development of human society through the primitive communism of early civilisation, the slave societies, the feudal period and into the present capitalist phase. He expected and supported some form of post-capitalist society, but he also acknowledged the progressive influence of capitalism in breaking the hereditary power of the feudal system and in harnessing the productive forces of technology. Under capitalism, production has been stimulated to the point where it is feasible to eliminate the daily struggle to meet the necessities of life; this productivity holds out the tantalising possibility of all humans being freed to seriously consider the quality of life. However, Marx also saw that, while the technical problems of production were being solved under capitalism, the problem of equitable distribution of goods remained a problem. He envisaged therefore that capitalism would bring about its own demise. He predicted that members of the new working class, alienated by deskilling and ever increasing demands for productivity, would be united by their common situation and would eventually organise in opposition and usher in a new age of freedom and democracy. Thus capitalism, the system that enabled the bourgeoisie to overthrow feudalism, would in turn produce its own 'grave diggers'. The 1917 revolution did overthrow nascent Russian capitalism but the revolution failed to establish a new democracy. At the risk of oversimplification, the same could be said for subsequent communist revolutions in other countries. Commentators differ as to why these countries did not establish working democracies, but clearly the failure to do so had much to do with the recent dramatic collapse of European communism.

In contrast to revolutionary change, the mechanisms that enabled capitalism to undermine the feudal system also ensure that capitalism itself remains fluid; change is endemic. The economic freedoms required for the market place have spilled over into the political arena where, at least in the advanced capitalist countries, the state is usually careful not to appear overtly oppressive. The accompanying development of democracy has resulted in a 'free market' for new ideas. The capitalist system offers large rewards to the successful and in doing so encourages the growth of meritocracy and taps more deeply into the innovative capacity of human beings than any previous system. Capitalism has shown a remarkable resilience and adaptability, and in many nations it delivers a continually rising material standard of living to the majority of the population.

In addition to these positive features, capitalism exhibits features that limit human progress. Capitalism has a logic based on the demand for a return on capital invested, and on the forces of competition. Thus the measure of the worth of ideas and innovations is strongly biased towards purely economic success. Furthermore, the investment capital which stimulates and supports business produces a return and so provides even more investment capital. This positive feedback loop generates ever increasing production and consumption but brings with it an inherent instability. Slumps, market collapses, unemployment and inflation are usually seen as the inevitable system responses to the boom and bust instability. A fundamental problem with the capitalist system is that human concerns are not adequately factored in, that is to say that the demands of capital are considered more important than the needs of people. Our present level of democracy is such that many people do not have their economic voice heard. Nonetheless, although we only have a stunted form of democracy, the fact that it is claimed to be at the root of capitalist society gives us a base from which to make changes.

It is not easy to make fundamental changes to any society. Each of the past phases of social development contained its own world view and an all-pervasive set of ideas and values. These ideas and values, the hegemony of the ruling class, provided stability and were accepted as the natural state of affairs - even by disadvantaged sections of society. A useful analogy is the Kuhnian notion of a scientific paradigm in which everything is viewed and interpreted from within the framework of a given set of assumptions. Today, for example, under capitalist hegemony it is difficult for people to imagine alternatives to wage labour and the private ownership of plant - it all seems to be the natural state of affairs and, under the accepted system, people are led to make choices which perpetuate that system. In this way, ruling class domination places restraints on people's purposive involvement in influencing the direction of society. The success of capitalist hegemony can be judged by taking the repeated failure of the political left to make fundamental social changes in Western countries and comparing this with the speed and apparent ease with which recent changes took place in Eastern Europe.

If one of the outcomes of general education is that people hold democratic ideals, then this may promote the development of democracy in society. However, we should not expect simply to define democracy abstractly and then have people put it in place, for this would ignore the dynamic nature of social reproduction and transformation. Furthermore, the process of change will require more than a belief in democratic ideals. In Section 4.1, the importance of educating people in democratic ideals was emphasised but nothing said about the mechanisms by which a principle such as that of communicative action could be implemented; nor was anything said about the political will that would be required. In the face of capitalist hegemony, simply educating people about democratic ideals is unlikely to produce change. If we wish a healthy democracy to develop, then people must be willing and able to ask fundamental questions, to seek reasons for why things happen, and be prepared to change things when necessary. A prerequisite for such a state of affairs would be to have a general population with a rational view of the world, a predisposition to think critically and a respect for evidence.

As it has developed over the centuries, science has evolved certain, rather exact and exacting procedures for assessing evidence and knowledge claims. It has also developed - at least among its advanced practitioners - certain attitudes such as the predisposition to analyse and the inclination to resist premature closure. It is reasonable to expect science education to help produce a population able to apply creativity and reason to changing society. After all, it is by the use of rational analysis and the creative application of reason that the international community of scientists produces reliable public knowledge about the world. Unfortunately, the outcomes of science education are undermined because the view of science and the world held by most practising scientists is not shared by all science educators. In the next chapter I turn to the views of science, to the outcomes of science education, and to one way of exerting democratic control.

CHAPTER 5 SCIENCE AND SOCIETY

5.1. Positivism, Technology and Lack of Control

Science has a very powerful and all-pervasive influence on modern society. The relationship between humans and their world has been influenced by a number of philosophies, for example the long fight of Christianity against magical beliefs. However, the most recent influences have been that of scientific thinking and our understanding of the material world. The general decline in belief in the supernatural is at least partly linked to scientific notions of tests and evidence, and the acceptance of the need of a physical cause for phenomenon. Similarly, scientific understanding of the heliocentric solar system, and of evolution through natural selection have altered perceptions of the place of humans in the universe. More directly, scientific knowledge fosters the rapid advance of technology which, in turn, alters the way we live our lives. While engineering inventions such as spinning and weaving machinery dramatically altered the rural face of Europe, it is the recent advances such as those in chemical and medical technology, and the ubiquitous silicon chip, that are perceived to be more directly linked to scientific research and development. Thus twentieth century technological changes and their effect on people's lives is likely to influence how science is viewed and the esteem in which it is held. No change is ever an unqualified influence for the better, and this leads some people to be willing or even eager to downgrade the status of science.

Democracy and science have developed together under capitalism, and in many ways science exemplifies an international, democratic community. However, while people rarely reject democratic ideas, science is often under attack and we need to look for reasons for this. A common starting point for the criticism of science, and for the advancement of an anti-science philosophy, is a fear of technocratic control. This fear has two components. This first component is the observation that technology controls people rather than the reverse, for example the invention of trains, cars and aeroplanes has had a dramatic and irresistible effect on demography and cultural diversity. The second component is the belief that scientific certainty means that there is a totally determined technical solution to every problem, and that a scientific approach to a problem removes from people any choice about the solution.

Some of the results of technology seem to justify the first fear, that of technology controlling people. However, it is not the scientific ideas and technological capabilities *per se* that alter our lives, but the political and economic decisions that are made about the use of technology. Ultimately, the impact of science is mediated through the structure of our social organisation. Which ideas are developed, and which ideas lie dormant, is only partly a matter of technical feasibility. The overriding factors are always economic ones that operate through the ubiquitous 'market place' (which in theory is democratic but in practice is distorted by the unequal distribution of economic power). Scientific literacy for all, which is the aim of some science education reforms, will not give citizens effective control over the influence of science and technology. Rather, we need to strengthen the role of democracy in society, for this would give citizens control over the institutions and processes of political and economic decision making.

However, while greater political and economic democracy is a necessary condition for controlling and humanising technology, it is not a sufficient condition; the scientific community too must play its part. In one sense science is value neutral because it gives a picture of how the world is, but at a different level the scientific community must be responsive to the social order in which science operates, and to the values on which scientific work impinges. Scientific research is a rational exercise, and its results are constrained by the behaviour of the real world, but decisions about where to put the research effort are open to prejudice, bias and undue economic influence. As a further complication, the results of science (the technologies available) have largely forged the material conditions under which decisions are made about research priorities. Thus a totally objective science is not possible, science itself is not immune from capitalist hegemony. For example, a major problem in setting priorities in the spending of public health money arises precisely because of the vast range of technically feasible, but very expensive, medical techniques available. Why these techniques have been developed ahead of others is a matter for debate but, once developed, they strongly influence further development. In this way, science sometimes generates ethical problems which, by itself, science has no warrant to solve (other than by offering a rational approach or by offering yet more technical possibilities). If we had a mechanism by which reasoned societal input could influence the direction of research endeavours, human concerns could be factored more strongly into the enterprise of science. Thus a strengthened democracy would influence the progress and direction of science.

The second fear, that of poor decision-making based on 'scientific certainty', arises from a belief in the narrow, positivist view of science. In this mistaken view, science is a strictly logical procedure for pursuing truth by objectively observing the facts of nature. This is an oversimplified and empirical picture of a scientific method that leads to claims of certainty of knowledge. Such a view is damaging to science and to society because it reduces the complex set of analytical, creative and critical behaviours that are the rational pursuit of scientific knowledge to the mindless following of an algorithm. It paints science as a reflexive rather than a reflective behaviour.

Philosophically, logical positivism was defeated several decades ago but a positivist view of science still lingers at the public level as an unfortunate and unintended outcome of traditional science education. If we are to produce rational, creative and critically minded citizens, there is an urgent need for science educators to exorcise positivism from science courses; fortunately, most recent reforms in science education indicate an awareness of this. Unfortunately, the post-modernist view, which is one of the alternative views of science, is no less objectionable than the positivist view.

5.2 Post-Modernist Non-Science

In the search for alternatives to positivism, there is no shortage of views on science. For centuries philosophers have questioned how theories are generated, how they are justified, and what the relation is between our knowledge and the external world. To these questions, sociologists of science have recently added the question of what motivates the work of scientists. Overall, views of science range from naive inductivism where scientists uncover objective truth by careful and unbiased observation, to the post-modern sociological interpretations of scientists' work as producing a culture-bound and inevitably relativist picture of the world. In the extreme, this latter picture suggests that modern science is just one of many equally valid ways of explaining the world, for example, Harman (1988) holds that the current scientific endeavour is simply a 'cultural artifact'. Modern science did have its immediate origins within European society, and modern science clearly carries historical baggage (lingering sexism in its operation and its research interests for example). However, it is not the case, as Harman claims, that a different society would have produced a different science. The explanation of the world provided by modern science is not just the 'best' in terms of the pragmatic criteria of being able to predict and control nature (Hesse, 1978); it can also be argued that it is 'true' in that it has uncovered some of the underlying mechanisms of the world (Harré, 1986).

If we go along with those who deny that modern science provides a privileged view of the world, we not only rid ourselves of positivism but we fall into an abyss where skeptical post-modernists, who have lost faith in reason, dismiss all knowledge claims as equally arbitrary and assume the universe to be unreliable in its behaviour and incapable of being understood. Such views lead to the continual mystification of both the material and social world, and in so doing they affirm, by default, the law of the jungle. Far from challenging the existing power structure, such ideas assist its continuation. In the extreme, the post-modernist world is one in which there are no absolutes, no standards and probably no shared meaning, for example there is debate over whether text has any meaning other than those taken from it by me, by you or by any other reader. In this view, people each travel along in their own (imagined) parallel worlds that they construct for themselves. To move to such a world-view is to be disempowered, for the real world and real power will continue to exist and to control peoples' lives. The only people who could exist happily in a post-modernist world would be safely tenured academics!

In the dark, nihilistic world of the skeptical post-modernist there is no knowledge and no possibility of progress (Rosenau, 1992). In such a world the practice of science is at best pointless and at worst a cynical sham that props up the existing power structure. However, the practice of science, as understood by scientists, is neither positivist nor post-modernist. Science is a robust and rational practice producing trustworthy knowledge, (Harré, 1986; Hooker, 1987; Lamb, 1991 and Ziman, 1978). Science is a boot-strapping operation. There is no rock-solid reference point, and no fail-safe scientific method. Knowledge that is generated by individuals must be communicated to the scientific community and turned into public knowledge. This process is subject to the strict moral code of science; members must only communicate what they believe to be true according to the epistemological standards of their enquiry. Since all scientists will be subject to socio-cultural influences on perception, believing something to be true is not the same as it being true. However, as a pool of public knowledge is established in the scientific community we need to ask what is the source of the commonality in what is believed? Some commonality will be due to the socio-cultural background that scientists share but, as Harré (1986) points out, for a modest realism to be defensible we need only claim that not all commonality has a sociological explanation. Scientific theories are not direct constructions of the world from objective observations, nor are they simply social constructions unrelated and unresponsive to reality. In the future, it is always possible that any theory may need radical revision or even be discarded, but it would be churlish not to acknowledge that the scientific community has a far better understanding of the world in 1999 than in 1899.

Modern science and the knowledge it generates are integral parts of almost every society on earth and - in every conceivable scenario for the future - they are likely to remain so. While science has brought enormous benefits to human beings, its application has not been without problems. One way of addressing these problems would be to strengthen the operation of democracy within society to give some measure of public influence over the application and future direction of science. Without some mechanism for public input, there is the danger that science will be perceived as intrinsically elitist and authoritarian and consequently people may be drawn to support post-modernist attacks against it. One of the consequences of this would be the loss of a powerful educational tool for the promotion of democracy.

5.3 Post-Modernist Science Education

Unless the public funding of science is affected, scientists usually ignore controversies about the nature of science. Without any formal training in the history and philosophy of their discipline, scientists can be effective in their work. Such is not the case for science educators because one of the outcomes of teaching will be to influence public perception of science and of scientific knowledge. Such perceptions will influence people's decisions and actions and will influence the reproduction and transformation of society. For these reasons, it is important that science educators be clear about what view of science they convey, as well as being competent in the scientific knowledge that they teach. Unfortunately, many science educators are no better prepared in philosophical matters than their scientist counterparts.

The goal I have set for science education is the production of citizens who are creative, critical, analytical and rational. In other words, I want citizens who share many of the values and attitudes of practising scientists. If science education reinforces a positivist view of science then this may limit citizens' critical and analytical attitudes, and suppress their justified skepticism. This would hardly encourage citizens to question the fundamentals of their society since they would be predisposed to accept information on the basis of authority rather than evidence. Most modern curriculum developers are well aware of the dangers of positivism and curricula are designed to avoid promoting a positivist view. However, if science education leads to the promotion of a post-modernist view of science and of the world, then this is equally dangerous because skepticism will be pushed to a level where it can destroy the very belief in 'meta-narratives' such as the democratic project.

I accept the need for a 'kinder science' (Rosenau, 1992), but hold that moderate realism shows science as both a human and humanised activity, and one that has the potential to be even 'kinder' under a fully democratic society. Positivist science does need to be rejected, but this does not mean that we have to embrace post-modernist non-science. A form of realist science, with an offer of reasoned choices within a reliable universe, provides a better model for education towards democracy than the random and chaotic individualism of post-modernism.

Knowledge claims about non-trivial matters need to be qualified, and complete certainty is not attainable. However, it does not follow that we cannot be justifiably certain of anything, nor does it follow that all views of the world are equally valid. In addition to trivial truths, such as 'This thesis is written in English' and personal knowledge such as 'I feel hungry', there are justified true beliefs within the realm of public knowledge. The discrete nature of matter is an example; whatever the precise nature of the structure of atoms, the description of a glass of water as consisting of discrete particles is more than a useful metaphor, it is a true description. The epistemological claims of science are of greater worth than any other when it comes to knowledge of the natural world. Thus questions of 'whose knowledge is of most worth?' and talk of 'personal epistemologies of teachers and students' (Shymansky & Kyle, 1992), must be carefully nuanced. In our efforts to rid science education of its positivist ancestry it is easy to step towards what Good (1993) describes as 'the slippery slopes of post-modernism'.

Unfortunately, and from the best of intentions, some science educators do risk sending their students down the 'slippery slope' by advocating post-modernist views of science. This is particularly (but by no means inevitably) a feature of science education reforms which address socio-cultural aspects. As an example of a sensible integration of socio-cultural aspects into science education, Jenkins (1992) claims that ‘young people’s perceptions of science as an activity which increasingly shapes the world in which they live may be far ahead of that which underpins much of school science education’. For this reason he advocates 'accommodating the political and social dimensions of contemporary science in ways that...have been marginalised within, or excluded from, school science curricula'. He is advocating the broadening of science education goals, rather than advocating a shift towards post-modernist views of science.

In contrast, O'Loughlin (1992) seeks to emphasise science as a social construct and clearly moves towards a post-modernist view. In a critique of Piagetian constructivism, O'Loughlin gives his view of the task facing science educators:

> 'Science teachers, therefore, face the simultaneous challenge of validating their students' personal ways of knowing, introducing them to the powerful speech genres of conventional science, and equipping them with an understanding of the fundamentally socio-culturally constituted ways of knowing that underlie science so that the process of doing science is demystified...'

I am happy with the idea of 'demystification' but not with a later statement. O'Loughlin ends ambiguously, stating that science should not only be demystified but that the students 'should not feel compelled to defer to the intrinsically authoritative power of the received view'. While this may be interpreted in different ways, some of which would be unproblematic, it is clear from an earlier remark that O'Loughlin views rationality itself as an artifact. Thus the very attempt at teaching science rationally is restricted from the outset. This raises the fundamental question of whether post-modernism is a coherent and empowering world view and a viable alternative to rationality. Now, while there may be a certain consistency to postmodern critiques, they are inherently disempowering because the implicit relativism removes the criteria by which people may criticise the status quo.

In an effort to produce a science education that is 'more authentic and inclusive', Cunningham and Helms (1998) seek insights from the sociology of science. One of those insights is that 'there is nothing extrordinary about science - its status stems from its purpose as a tool of persuasion', which is dangerously close to a relativist view of science. Ogawa (1995) makes this relativism specific by linking multiculturalism with 'multiscience'. Such views have been vigorously attacked, for example by Gross and Levitt (1994) and Matthews (1995), and gently but firmly refuted by Loving (1997).

In some other proposals for reforming science education, it is unclear whether it is the goals of science education that should be altered, or whether we are being asked to adopt an alternative view of science. Hurd (1994; 1998) considers the nature of science and also offers a socio-cultural dimension based on the changing nature of society and on the characteristics of today's young adolescents. Hurd's goal is to have a curriculum 'that can be lived and which has cultural as well as scientific validity' and which results in students knowing themselves and their culture. He expresses concern for cultures such as inner city youth, but leaves it unclear what is his recommendation. Should we adjust the delivery of science education so that the scientific (dominant) culture is made accessible to everyone, or should we devise new curricula based, for example, on 'black science' or 'working class science'. In his earlier paper, Hurd (1994) supports a post-modern science which, he claims, is embedded in social and cultural contexts. But was science ever not so embedded? Only the positivist view of science places it in some sort of objective vacuum. Real science takes place in, and is subject to, socio-cultural influences, but it is also ultimately judged by the behaviour of the real world. This key feature of science makes science education invaluable for a training in rational decision-making on the basis of evidence. I suggest that the ambiguity over the need to adopt an alternative view of science arises from the failure to distinguish between realist science, which takes place in a socio-cultural context, and the post-modernist view that science is simply a social construct.

Some science education reforms express legitimate and commendable concerns about the inequalities in society and clearly express a hope for the future. For example, Kyle (1991) wishes 'our youth to fulfil their dreams, rather than settle for the tarnished present-day reality.' Kyle's ideas for escaping this reality through cultural pluralism, diversity and relativism have been criticised by Hostetler (1993) and I have a further criticism. If there is concern about inequality, then questions must be asked about what are the characteristics of the dominant social group that enables it to maintain its power over other cultures and subcultures? It is significant that in his paper, which is subtitled Hegemonic Control vs Counterhegemony, Kyle refers to conservative ideology and elites, but does not mention capitalism. If socio-cultural aspects are to be taken seriously then all the aspects need to be carefully identified. The disadvantaged student will only be further disadvantaged by being led into a make-believe, post-modern world. This adds yet another reason why it is important that science education avoid any relativist view of science and of the world.

There is a further reason for teaching realist science, a reason that is directly related to the social and political context. In the absence of any credible alternatives, we must conclude that modern science provides the best understanding of the world that we have. Similarly, democracy is currently the best form of social organisation. Leaving aside cynical self-interest, the defence of democracy is at least one of the motivations for the powerful countries of the world to intervene in places like Bosnia or Iraq. Even a benign state run by a conglomerate of paternalistic companies would be, or should be, an unacceptable substitute for democracy. No culture should expect to be free to choose a non-democratic path; in the modern world social organisation is not relative. It has also been argued that there are superordinate notions that transcend any specific cultural situation and consequently neither rationality (Blake, 1997) nor ethics (Puolimatka, 1997) can be taken as relative. Given this, it would seem inconsistent for anyone to teach science as just one way of understanding of the world.

I agree that science education is in need of reform, both in terms of the curriculum and in the way that science is taught, and I agree that positivist elements need to be exorcised. I have argued, however, that we must be careful not move to the extremes of post-modernist 'science', and that moderate realist science provides the suitably humanised replacement for positivist science. I agree that compulsory science education should be designed for the general population, rather than for a specialist group of future scientists, and I have sympathy with the notion that science education should lead to 'empowerment' (in some general sense of giving citizens more control or decision making ability). However, we must be careful not to ask too much of science education. The role of science education in this change is limited to providing citizens with rational, critical skills and attitudes. Citizens will improve their society by using these skills and attitudes to push for an extension of democracy under which all voices are heard. Democratic ideals, and related skills and knowledge, will be taught in general education, but the nature of these is beyond the scope of this thesis.

In the next section, I will show how citizens may mount a democratic challenge to the applications of science and to the influences these applications have on their lives.

5.4 Science, Expert Knowledge and Social Control

To control the effect of science and technology on people's lives we must find a way of acknowledging the expert nature of scientific knowledge without acquiescing to all the demands of experts. We must also find a way of challenging decisions without resorting to the excessive skepticism of postmodernism. As I have argued previously, although postmodernism uses the rhetoric of empowerment, it is ultimately disempowering. I also hold that we are unlikely to be able to get citizens to the stage where their science knowledge will be sufficient to challenge scientists in their own field. Furthermore, the goals the STS movement to integrate scientific knowledge with a range of cultural, social, political and economic aspects are well meant but overly ambitious.

The interaction between expert knowledge and political decision-making is, like all real-life, inevitably complex. As Ulrich (1983) describes, Thomas Hobbes (1588-1679) first distinguished between those political questions which rational enquiry and scientific knowledge could answer, and those political questions which required normative, subjective decisions. Hobbes' motto was 'power rather than truth makes the law' and, in Hobbes' scheme of things, science was to inform those in power about the proper means for their political ends. With the Enlightenment, came thinkers such as Jean-Jacques Rousseau who countered Hobbes' motto with one of his own: 'truth rather than power makes the law' (or perhaps more correctly, truth rather than power should make the law). That this has come to pass if only partially, can be seen in the last few decades when politicians have increasingly paid attention to environmental issues for example. The irony is that technical aspects of issues can themselves easily become the ends. The political process is then relegated to the task of finding means to technically derived ends, and this subverts the democratic process because experts and advisors are not accountable to the public at large. This subversion of political debate by expert knowledge is amply illustrated by the extent to which advice from treasury and the reserve bank is accepted almost unquestioningly by both right and left leaning governments. This is the 'technocratic' model of decision making, criticised by Habermas (1971), where the rationalisation of power occurs because the 'logic of facts' replaces political debate. Knowledge no longer serves power, knowledge is power.

So far, we have a decisionistic model where knowledge is simply used for political ends and a technocratic alternative where democratic political decision making is subverted by the claimed privilege of expert knowledge. Ulrich (1987, 1988, 1994) develops a theory of Critical Systems Heuristics that offers a way forward. Ulrich's theory has two basic requirements - ethical behaviour by experts and critical thinking by citizens. I will deal first with the ethical behaviour of experts. This requirement does not imply that experts currently act unethically, although there may be times when some do. This ethical requirement is for a new type of whole-system ethics; one that is capable of considering, for example, environmental responsibilities on a global scale; one that is future-oriented in that the consequences of our actions on future generations are considered; and one that is critically oriented in that the demand is not just to be moral but to continually evaluate the limits of our moral judgments. To be truly whole-system is, of course, an impossibility - no one could take into account all factors because interconnectedness is a characteristic of human existence. In practice, decisions are made, and actions are taken, after a system has been defined by drawing a boundary around merely a subset of all the possible factors. Often, this boundary is then taken to mark out the extent of the system (that is, features outside of the boundary are assumed to be irrelevant) and the boundary is taken to declare the region within which experts can make priority claims to knowledge. For example, applications of scientific knowledge, which produced the 'Green Revolution' in Third World agriculture, are actions that had behind them the best of intentions (at least scientists had the best scientific intentions). Unfortunately, they were also applications for which the downstream social and economic effects had not been fully considered. Some would argue more cynically that economic dependency was, in fact, a conscious but covert objective of the Green Revolution. However, unless we ascribe bad intentions to all involved, the point at issue is not why problems occurred but how could they have been anticipated and avoided. Ulrich's solution is for experts to engage in a 'sweeping in' process that identifies a wider and wider range of factors, and in a 'critical' process that sets boundaries but acknowledges those factors which have been excluded. This critical process makes greater knowledge demands on people, and the issue of moral competence shifts from good will and personal responsibility (volitional ethics) to knowledge and understanding of the total system that is involved (cognitivist ethics).

Simply acknowledging and making problematic the boundary conditions is not, in itself, sufficient to avoid inappropriate application of science. To do this we need the second of Ulrich's two basic requirements - critical thinking by citizens. Ulrich argues that in setting boundary conditions the experts are forced to go outside of their realm of expertise. Thus citizens may challenge the boundary conditions set by experts and, without any particular expert knowledge, citizens may argue for their own:

> 'As against the expert's boundary judgments, [citizens] can with equal right and with overt subjectivity advance their own boundary judgments, thereby embarrassing the expert for being unable to prove the superiority of his boundary judgments by virtue of his expertise.' Ulrich (1987) p 282

Of course, citizens lose their advantage when challenged to prove their own boundary judgments, but the way has been cleared for open and democratic debate about the boundary assumptions and about the ethical issues involved. That neither side can produce an entirely rational justification for their case 'provides no sound argument against a systematic effort to promote critical awareness with respect to our failure to be comprehensively rational' (Ulrich, 1994). Furthermore, Ulrich argues that;

> '[u]ncovering the lack of comprehensiveness - the unavoidable selectivity - of [experts'] designs and then systematically tracing the practical applications of that selectivity is perhaps the only way to prevent the difficulties in question from becoming a source of systematic deception.'
> Ulrich, 1994, p 36

Thus the process is one of making transparent the reasoning and the lack of reasoning behind technical decision making.

I suggest that 'pure science' research could be challenged in a similar manner. As a rather simplistic example, it would be legitimate to ask if such and such research should be funded while there are people starving in the third world. The outcome will not automatically be to shut down the research and divert funds into food aid, because sending food to a country does not necessarily solve the underlying problems of internal corruption, interference by Western multinationals ... and so on. The outcome should be that the issues are widely debated by all interested parties. It is not that debate is lacking now, it is just that current debate is often framed in terms of humanism (uninformed by science) versus science (unleavened by humanism). Reasoned argument lies at the heart of a successful democracy and, while citizens may successfully challenge boundary judgments without any expert knowledge, it is clear that citizens will need rational and analytical skills and attitudes. The contribution of science education should be to develop in people the skill of thinking scientifically. In so far as STS and science literacy programmes develop scientific thinking, I believe them to be useful but, in so far as such programmes set goals of developing expert competencies, I believe them to be naive.

In terms of setting the widest possible boundaries, I suggest that for science and for science education, for education, and indeed for most of our social activity, the goal should be to attempt to answer the following question:

'Can we secure improvement in the human condition by means of human intellect?'
C. West Churchman. Quoted in Ulrich (1998) p 16.

Are we in danger of setting science up as a new religion? The answer is a clear yes and no. The answer is yes in the sense that religions give people ideas (or a faith) and these can produce real effects through people's decision-making. Science can develop the idea of rational, critical thinking and this can affect people's world view and affects their decision-making and behaviour. In turn, this produces real effects in the reproduction and transformation of society. The answer is also yes, science is a religion in the sense that ethical values are embodied in religions and in science. Science carries its own ethical values such as honesty, integrity and even a 'cosmic piety', as Bertrand Russell put it, developed as our growing knowledge serves to emphasise how much we don't know. But, to the question of whether science is a religion, answer must also be no. To the extent that religion might not encourage questioning of its faith, and the extent that religion might teach its values simply as rules, science is not a religion. Perhaps it would be safer to say science *should* not be a religion, for we must bear in mind those like Feyerabend who criticise present-day science, and especially science education, for being an authoritarian ideology that neither fosters nor accepts dissent. Real science has at its heart a positive and healthy skepticism, and a process of rational questioning - science education must foster in all people the ability to think scientifically. People may then bring this skill to the task of improving the human condition by means of the human intellect.

What about thinkers such as Thomas Aquinus from the Christian intellectual theological tradition, or religious philosophers from other cultures - were they not rational?, did they not try to improve the human condition by means of the human intellect? Clearly the answer to both questions is yes. For a long time in human history, religion provided a way of thinking about the world and religion was the source of conscious, ethical theorising. Beyond the cynical employment of the authority of the church for personal gain, and beyond the mindless ideologies aimed at gaining obedience rather than thoughtful reflection, there lies an intellectual tradition that is critical, analytical and reflective. A full discussion of the relation between thinking in this tradition and scientific thinking is beyond this thesis. However, my claim is that, for inducting children into critical and analytical thinking, scientific investigation of an objective physical world is a more accessible educational context than ethical theorising about our socially constructed world.

I have given general indications of the role that science education might play in social changes and in improving the human condition. In the next chapter I will work towards defining a more specific outcome for science education.

CHAPTER 6 SETTING A GOAL FOR SCIENCE EDUCATION

6.1 Science, Psychology and Science Education

What exactly is science education? What should teachers and students be doing in a science lesson? There a many simple but quite different answers. Children should be learning about everyday phenomena and common devices, or children should be learning the powerful generalisations of science. Children should be learning the content of science, or children should be learning the processes of science. Children should be following a hands-on programme, or children should be thinking about what counts as evidence ... and so on. For their part, teachers should be following the interests of the children, or teachers should be designing a logically structured programme. Teachers should be learning along with the children, or teachers should be making use of their subject expertise ... and so on. Perhaps the answer to our questions should be 'all of the above'? The outcome of science education are usually concerned with learning in science and learning about science, with the traditional bias being towards learning in science. Indeed, even recent STS curricula and constructivist pedagogies still have learning in science as a main goal.

If learning in science is important, what do we know about it? Chinn & Brewer (1998) claim that 'there are few if any comprehensive theories of knowledge acquisition' (p110), and within their paper they develop eight questions:

> 'What is the nature of knowledge change?
> Are there intermediate stages in knowledge change?
> What initiates knowledge change?
> What factors influence knowledge change?
> What is the fate of the old knowledge and the new information after knowledge change occurs?
> What is the relationship between belief and knowledge?
> What factors influence belief change?
> What changes in meta-awareness occur during knowledge change?'

For each of these questions a number of positions are outlined, some of which are at least partially conflicting. For example, in response to the final question about meta-awareness, three positions are identified by Chinn & Brewer. One is that of Kuhn (1989) in which it is claimed that children remain largely unable to reflect on their theories and that beliefs about the world remain largely at an implicit level. A second position is that as children learn, they become increasingly aware of the principles that govern their knowledge, and become increasingly able to reflect on their knowledge (Karmiloff-Smith, 1992). (It must be said that later research leads Kuhn (1993), as well, to a similar conclusion.) The third position is that learners are always aware of their learning.

In the last two decades the idea of producing 'conceptual change' has been a dominant factor in science education theorising. Not surprisingly, given the range of positions across the range of questions given by Chinn and Brewer above, the common feature of research in this area is the importance placed on conceptual change; how this conceptual change takes place and how change can be facilitated are the points of difference.

In recent efforts to understand science education, focus has shifted from curriculum development and pedagogical practices to the the history and philosophy of science and to the cognitive processes involved in gaining, processing and evaluating knowledge. The inclusion of history and philosophy of science has been advocated in order to put a human face on science and to facilitate the learning of science concepts (for example Stinner & Williams, 1998, and Matthews, 1994), in order to avoid the 'scientistic legacy' of science (Duschl, 1988), and to achieve all of these things (Hodson, 1998). Conceptual change has been related to both the nature of science and to developmental psychology; first by comparing the thinking of children with the thinking of scientists, and second by comparing the cognitive process of conceptual change in learners with the process of theory change in scientists or within scientific communities.

Much of the early conceptual change theorising was concerned with trying to escape from the presentation of science as a logical and structured progression of ideas. Put in terms of the nature of science, the early ideas were concerned with escaping a presentation that was almost exclusively concerned with the context of justification. Duschl (1988) suggested that learners' disenchantment with science lay with students not knowing how scientific knowledge came to exist, rather than with any inability to learn the fundamental scientific concepts. In particular, Duschl asks:

> 'how does science remain a rational enterprise in the mind's eye of the students if theories evolve (and they do) and if students do not understand the mechanisms or criteria for guiding such changes?" Duschl (1988) p58

The answer suggested - inviting philosophers, historians and sociologists of science to contribute to curriculum design - turned out to be a little simplistic, but so too were the early conceptual change models. For example, based on the theory change models of Kuhn and Lakatos, the pedagogical moves for producing conceptual change proposed by Posner, Strike, Hewson and Gertzog (1982) were based on two stages. First, students were to meet anomalous phenomena that would cause dissatisfaction with students' existing ideas. Second, commitment would be transferred to a new idea that was seen to be more coherent, plausible and fruitful (in terms of its explanatory powers). That this was not entirely successful is, in hindsight, not surprising. Duschl and Gitomer (1991) suggest that the Kuhian and Lakatosian models imply a hierarchical view of conceptual change in assuming that 'changes in central commitments' will produce 'changes to to other ontological, methodological and axiological commitments'. Duschl and Gitomer go on to develop a model based on the more piecemeal approach to theory change of Laudan, and to support the ideas of Carey (1986) and Giere (1988) that there is much in common between scientific theories and cognitive schema. Teaching students the procedural knowledge for evaluating observations and data in terms of evidence for theory change then assumes great importance in move towards achieving conceptual change. In other words, the development of learners' epistemologies must be taken into account in any teaching scheme. In their 1991 paper, Duschl and Gitomer explore the issue of assessment, particularly as it relates to a 'portfolio culture' but, while I accept this as important, assessment is one of the issues that I have excluded from the scope of this thesis. They also touch on the notion of 'teacher empowerment' and the inherent complexity of the teaching and learning environment and I will return to the ideas in Chapter 9.

There are alternatives to conceptual change theories. Thagard (1992) suggests that it is the relationships between concepts that builds new knowledge rather than changes to the concepts themselves; diSessa (1993) claims that knowledge is built by refinement of 'phenomonological primitives' which are small pieces of knowledge produced by experiences; and Vosniadou & Brewer (1992) envisage knowledge building in terms of an evolving sophistication of learners' naive frameworks. The idea of conceptual change has also been supported and elaborated. Drawing on work by Lemberger (1995), Hewson and Lemberger (1999) suggest that knowledge of the status (intelligibility, plausibility and fruitfulness) that students accord to concepts is sufficient for teachers to design instruction and evaluate learning. Work by Beeth (1997) supports the idea of status as an important instructional factor, but also suggests that judging something like the 'fruitfulness' of a concept presupposes a level of metacognitive processing in students. Thus Beeth sees the provision of metacognitive tools, and provision of opportunities to practise the use of such tools, as a crucial, additional task for teachers. This call echoes the point made by Duschl and Gitomer (1991) about the need to attend to student epistemologies.

However, the notion of conceptual change has not gone unchallenged. Linder (1993) argues that less effort should go into changing student concepts and more effort be put into;

> 'enhancing students' capabilities to distinguish between conceptualisations in a manner appropriate to some specific context - in other words, being able to appreciate the functional appropriateness of one, or more, of their conceptions in a particular context, making science education into a functional base from which to view the world.' p 298

Ohlsson (1999) suggests an explanation for the commonly observed failure of 'anomalous data' to trigger conceptual change in learners. He proposes that the level of commitment with which children hold concepts is low, and that the failure to trigger conceptual change is because such data may not actually appear 'anomalous' to the child. The nature of understandings held by children is also questioned by Rowlands, Graham & Berry (1999). They argue that children do not hold concepts in any well defined or well developed way and that this explains the absence of any coherent and successful paradigm of constructivist/conceptual-change teaching. Their scheme (for mechanics) gives a Vygotskian role to the teacher in building alongside the children's ideas the idea of idealised abstraction 'which has as its starting point the logical structure of Newtonian mechanics rather than the cognitive state of uninstructed students'. They contend that;

> 'It is not the presentation of facts as anomalies, but the presentation of anomalies as props and hints to arouse higher mental functions. The construction process is not the reinvention of the Newtonian system ... rather, it is the class understanding the way the Newtonian system speaks of the world, and in the way that each student makes the system his or her own.' Rowlands, Graham & Berry (1999) p 267

Strong links have been proposed between the thinking of children and the thinking of scientists. The 'theory theory' is based on the close analogy between cognitive development and theory change in science. It is generally taken that children's development of ideas tends to mirror the historical development of ideas in science, although Gopnik argues the reverse. In her characterisation, 'it is not that children are little scientists but that scientists are big children', and indeed that 'science may be successful largely because it exploits powerful and flexible cognitive devices that were designed by evolution to facilitate learning in young children', Gopnik (1996). I find interesting the idea of the evolutionary selection of traits and these are related to some of the ideas in section 3.3. However, if the nature of the concepts held by children are different to those held by scientists (Ohlsson, 1999 and Rowlands, Graham & Berry, 1999) and the commitment with which they are held is different, (Ohlsson, 1999) then this does throw doubt on the depth of the metaphor linking theory development in science and conceptual change in children. Furthermore, Hewson and Lemberger (1999) reject the need for a theory of theory, pointing out that theory change happens within a community of scientists whereas conceptual change is necessarily an individual affair. The linking of historical development of ideas with development of concepts in children has also been questioned. For example, Grandy (1997) says of children's 'intuitive physics' that it;

> 'bears many resemblances to the sophisticated neo-Aristotelian physics of the sixteenth century, but it would be a mistake to treat them as identical. And the motivations of sixteenth and seventeenth intellectuals were different in many very important respects than those of our current students.' p 51.

Finally, with regard to the general analogy between theory change in science and cognitive development in children, I believe that Levine (2000) has made some apposite observations. He argues that, in developing the model of theory change in science, Kuhn was inspired by Piaget's study of conceptual development in children. Further, he argues that Piaget, in developing his theories of conceptual development in children, drew on analogies from the history of science. Levine concludes that there is enough evidence of circularity to cast doubts on any claim made, on the authority of Kuhn or Piaget, for parallels between the thinking of scientists and that of children.

Other ways of conceiving of children's knowledge-building in science have been proposed. Ohlsson (2000), casts Kuhn's paradigm shift as a naturalised version of Poppers falsification principle, and he further advocates moving to a naturalised paradigm of cognitive change. In his view, all cognitive change is 'a side effect of activity', rather than cognitive change being a process for accounting for larger and larger bodies of evidence. Ohlsson (2000) claims that our knowledge structures undergo changes as we engage in intellectual activities. In addition, Ohlsson's view is that:

> 'which change occurs ... depends primarily on which knowledge structures become active and how they jostle each other in the person's mind and not on the purpose or meaning of the activity. Consequently, there might not be any semantic or rational connection between the activity and the resulting change in knowledge.' Ohlsson (2000) p 184.

Schwitzgebel (1999) takes a very minimalist definition of a theory as something that provides (good) explanations and he proposes that theory-building could be explained by the existence in children of a 'drive to explain'. Duschl, Deak, Ellenbogen & Holton (1999) among others raise objections to the 'drive to explain'. In particular, Duschl et al. note that Schwitzgebel's notion of drive smudges the distinction between everyday thinking and scientific thinking, and it also favours theorising as an individual activity, rather than a socially mediated activity. Duschl et al. go on to present a version of theory building within specific domains which involves children in boundary crossing. This boundary lies between thinking that involves common-sense explanations based on sense perceptions and thinking that involves scientific theories based on theory-driven observations. This differentiation between types of thinking ties in with the idea of advances in science itself, which I proposed in Chapter 3.

While it is important to tease out what science education is, I would like to return to what I see as a key goal for science education - building a rational population. The further development of democracy and its continued operation at new, higher levels requires a rational population, not one paralysed by fear or political impotence, nor one driven by economic necessity. Not that I believe that the production of a rational population will automatically eliminate violence, disempowerment or poverty, but without rationality and critical skills people may never thoroughly question the origin of such evils. In the next section I will look at which science education goals will help achieve the overall goal of furthering democracy.

6.2 Science Education as an Agent of Social Change

What outcomes are currently set for science education? Unfortunately, the very success of science encourages us to take the learning of science for granted, and to ignore the need to set explicit science education goals. For example, Anderson (1992) presents a detailed account of the complexities of curricula reform but mentions goals only in the last section, and then almost incidentally as 'largely a value question [that is] often overlooked in the research context'. To his credit he goes on to acknowledge this as 'critically important...in that we do not have a consensus on what educational goals ought to be pursued'. In previous years, outcomes have been derived and justified in terms of the content and structure of science. Hirst (1974) makes the case for science as a specific form of knowledge but, while there are many aspects of this that I might want to defend, the influence of such a view on science curricula has been justifiably criticised as producing a science education designed mainly for the next generation of experts. Current replacements for these expert-biased curricula are based on the slogan, 'science for all'. These too have their problems, for if the scientific discipline does not provide appropriate structure and aims for science education, what does? Even the constructivists have failed to grapple with this problem. For example, Bell (1991) describes the curriculum seen from a constructivist perspective as 'a series of learning tasks and strategies' which will 'enhance the likelihood of conceptual change within a knowledge area'; constructivists' concerns are with the narrow goals of individuals' learning of science. In contrast, Science-Technology-Society (STS) and scientific literacy curricula do have goals that are extensive. However, STS goals are often overly-ambitious, a feature which produces its own set of problems (Shamos, 1988; Millar, 1996).

I wish to site science education in the context of social change but to set concrete aims and outcomes that have close links with the business of science and that are clearly achievable within the context of science education. We must not make the mistake of taking too much responsibility on science education (as has happened in STS), nor should we narrow the goals to something like 'conceptual change' (as some constructivists have).

I start by asking where science education should be headed and what its goals should be. I have assumed that the primary justification for teaching science to all children is that it is able to improve the quality of human existence by contributing to the advancement of democracy. Having this justification for science education raises two main issues; first is the need to flag inherent difficulties in producing social change and the second is to determine what science education outcomes would best serve the goal of social change.

The first issue is to note that producing coherent social change is no simple matter and this issue has been dealt with in Chapter 4. At one level we are autonomous individuals but, at another level, our behaviour is determined by the historical milieu and social grouping into which we are born. Our genetic predisposition, along with family, social, political, economic and other cultural forces, develops our 'world view' which is the framework for our intentional actions. However, we do not live in a deterministic world. Formal education is one of the cultural forces shaping our world view but, despite the fact that schools themselves are a specific cultural product, education does provide one weakness in the fabric of cultural hegemony (see for example Willis, 1978). Our society is not so monolithic that it can prevent teachers as individuals from making a difference.

The second issue, that of determining concrete outcomes for science education, can be approached by considering the specific skills needed by citizens in promoting social change. If citizens are to question rather than simply accept the existing social order, they will need a critical frame of mind; if citizens are to suggest alternative solutions they will need a creative flair; and if citizens are to carry out changes they will need self-confidence and trust in others, faith in rational problem solving, and a method of continual critical review. Such characteristics are demonstrated reasonably consistently by members of the international scientific community (although it is fashionable in some quarters to deny this) and thus it is important that the public know something of the workings of science and of the commitments of scientists. As science itself is a quintessentially rational enterprise, science education can help foster the skills and attitudes needed to conduct human affairs in rational ways. How these skills might be developed is the subject of Chapter 7. In the meantime, I must sound a caution that scientific rationality is an essential but by no means sufficient condition for the proper conduct of human affairs; compassion, altruism, courage, and other human attributes are also important. Science education must be seen in the broad context of general education and the development of an overall world view. People's world view helps mould their decisions and actions, and in this way people's world view influences the reproduction and transformation of society.

6.3 Science Education and Measured Commitment

The relationship between world view, general education and science education is illustrated in figure 1. One of the two main contributors to a person's world view is their experience, and one of the components of experience is schooling. What is taught in science education, and how it is taught, will influence people's world view and, consequently, the conduct of human affairs.

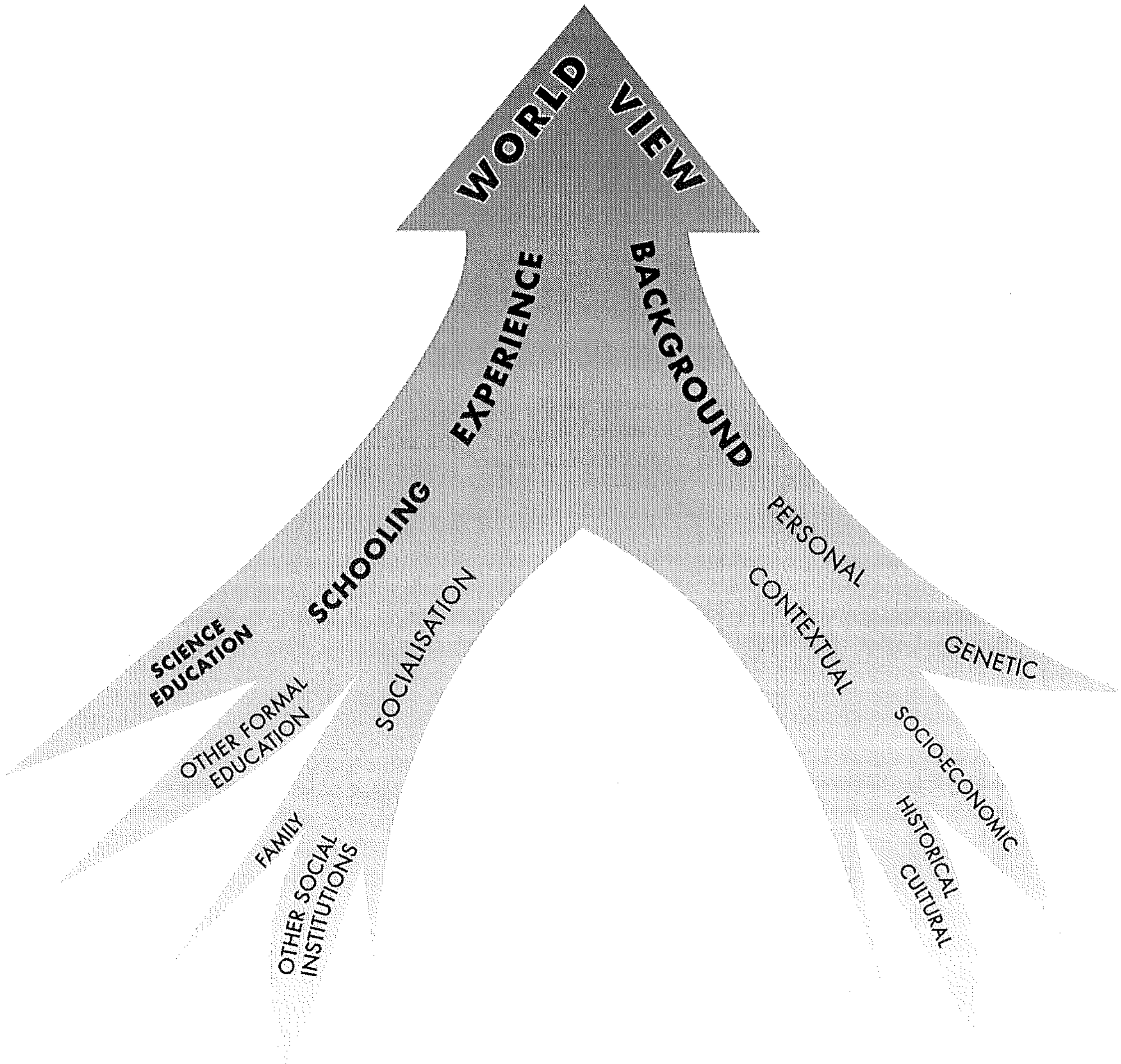

Fig 1
Showing the contribution made by science education towards the development of a world view.

The potential influence of education, and science education, gives great importance to the outcomes that we set for these endeavours. This raises the questions of which science education outcomes will have a desirable effect on the world view? and how might we go about achieving such outcomes?

One inevitable outcome of science education is the development of a view of science. Views will be derived from both what teachers teach and how they choose to teach it, and these views may be promoted consciously or quite unconsciously. Since science has a strong influence on our lives, people's view of science will influence the development of their overall world view. It is therefore crucial that science educators consciously develop in their students a view of science that will foster rational, critical thinking. One of the views of science produced in the past was the rather simplistic, positivist one. This has been largely discredited only to be replaced, in some quarters, with the equally distorted, relativist view of the post-modernists. However, post-modern criticism can be credited with causing realist philosophers of science to develop a more sophisticated understanding of science (Aronson, Harré & Way, 1994) and it is argued by Cole (1992) that it is through the 'new realists' that the public perception of science will be altered for the better. I will argue in Chapter 8 that the commitment we ask of students in order to learn science requires that the search for truth be a goal of science. This favours a realist view of science.

For science educators, one of the challenges in developing a realist view of science is to teach science content that is beyond all reasonable doubt, while at the same time maintaining a scientific skepticism in their students. This matter is dealt with in more detail in Chapter 7. In the meantime I find a useful way of thinking about this problem is provided by Norris (1997). His solution involves teaching science in such a way that non-specialists develop what he calls a genuine 'intellectual independence' (Norris, 1997). As a result of this sort of teaching, non-scientists should be able to place an 'epistemic distance' between themselves and scientific knowledge. Norris suggests that there is a balance point between, on the one hand, believing without question everything that science says and, on the other hand, being skeptical to the point of pathological doubt. I take this balance point to [illegible]ing a 'measured commitment' to specific theories. Such a commitment requires that, within their study of a science topic, students develop a commitment to a theoretical view based on understanding, rather than faith. I will argue in section 8.2 that having such a measured commitment allows the possibility of students revising their commitment on the basis of further evidence or a better theory. In this way the limited goal of 'measured commitment' (to specific theories) gives a route into experiencing and understanding the process and commitments of science itself.

What I have done is to define a single outcome for science education, that of producing in children a 'measured commitment'. This can function as the key goal for science education because reaching it implies that learners have both an understanding of (some) science concepts and an understanding of how science works. In reassessing their commitments, children will engage in rational, critical thinking. In Chapters 7 and 8, I will expand on what it means to be teaching science, and I will return to the idea of measured commitment in section 8.3.

CHAPTER 7 MEETING THE AIMS FOR SCIENCE EDUCATION

7.1 Three Aims for Science Education

How will we establish a measured commitment? What are the specific goals that willl contribute to this? In this section I set out three fundamental aims for science education. Their importance is twofold. First the aims must help children understand science and scientific knowledge and build a measured commitment. Second, the aims must help science educators to keep their nerve in the face of post-modernist attacks. If we misguidedly adopt relativist or other emasculated forms of science, then we inadvertently give up on rationality and the possibility of human progress. The aims themselves are not particularly revolutionary in terms of teaching science, but their justification within the wider social and political context is new.

The first aim is that children should understand that scientists are successful in developing an objective understanding of the world even though they do not have a fail-safe method, but that science is fallible (thus avoiding a positivist view). By meeting this aim we avoid the dependency on authority that positivist science education is likely to engender. Furthermore, in the process of developing democracy, citizens will require considerable confidence and perseverance to reassess goals and actions when the complexities of the real world cause well-planned actions to produce unwanted results. Thus it is important that science education demonstrate that a fail-safe algorithm or method is not needed for rational and successful knowledge-building. Otherwise empiricism may lead us to conclude (from observations of human behaviour) that humans are naturally and inevitably individualistic and competitive, and that a better society is against human nature. Conversely, it is easy to fall prey to rationalism, where idealists are content simply to construct models of 'how things should be'. To counter these traps it is possible to present realist science as a successful but not infallible blend of observation and theorising. In science a democratic community of enquirers engages in what Harré (1986) characterises as 'not only society's greatest intellectual achievement but also its greatest moral order'.

A difficulty in achieving this first aim is that fallibility lies at the frontiers of science and for the standard science content taught there is no reasonable doubt. While we can have learners undertaking real investigations into topics that are unknown (to them), this can lead either to stopping at students' individual and idiosyncratic theories (which is not science) or to teachers eventually using their authority to inject an appropriate version of the accepted view (which is not science). Some teachers adopt for themselves the role of naive learner and attempt to do some subtle guidance of the learners, but this seems to fail Portelli's honesty criteria (Portelli, 1993). A cooperative learning approach, where a class works on a single problem, and differing theories are argued out, may come close to the way 'real science' is conducted by the scientific community. Some 'interactive' or constructivist teaching methods contain elements of this as they are based the notion that knowledge is socially constructed. However, constructivists often see the social context as helping construct individuals' knowledge, rather than the individuals in the class attempting to negotiate some agreed public knowledge. (Caution is also needed in the adoption of constructivist methods because some constructivists - for example, Hawkins, (1994) - are too closely associated with relativism.) One further method of introducing genuine uncertainty and fallibility into classroom work is to use 'real life' problems with which the learners can become involved - a common example is some sort of local environmental issue. Such issues do raise awareness and do involve people critical thinking and in social action. However, the background science of real life issues is often very complex and we risk oversimplification and, even worse, the reinforcement of beliefs which are held on grounds other than the thorough examination of evidence. Overall, if we wish children to learn about the success, failure and fallibility of science, it may be best to use case studies of historical or current scientific work.

The second aim is that children should value scientific knowledge as the best we have (so limiting skepticism to a justified level). At the same time students need to recognise that there are limitations to the authority of science (see section 5.4). The issue of public versus expert knowledge is important as it relates to the notions of openness, honesty and trust in a democratic society. Where there is an absence of trust the public feels alienated and powerless, and may readily compensate for this by embracing a disempowering level of skepticism and a belief in irrational and unscientific forms of 'knowledge'. This can only damage and delay the growth of democracy. I would not wish to inculcate a blind faith in science and scientists, because this would be a return to a positivist perception - there needs to be developed in students a critical frame of mind coupled with a healthy respect for evidence. However, it must be underlined that even the most successful science education will not raise the general level of 'science literacy' to the point where lay citizens can legitimately dispute the validity of scientific knowledge or arbitrate between claims of professional scientists. However, given suitable critical and analytical skills, there are ways in which citizens may challenge the applications of science. Furthermore, there may be ways of democratically influencing the nature and direction of scientific research, as I indicated in Chapter 5.

I noted in Chapter 6 that the impact of scientific and technical matters on our lives leads some science education reforms to advocate raising general science literacy to the point where there could be informed public decision-making. Against this, Kelly, Carlsen, and Cunningham (1993) argue that science educators should 'retire the idea that by learning science citizens will be automatically equipped to make good public decisions' and that 'an over reliance upon the mastery of scientific facts may make people more, not less, helpless'. Now, while I am in agreement with Kelly et al. on this, I do not concur with the general thrust of their paper which is to use a sociological critique to weaken science as a privileged view of the world. Interestingly, although Kelly et al. embrace an emasculated view of science they have cold feet about expressing this to children for fear that children might "carry away from their science studies an incapacitating distrust of science's motivations and findings or a belief that science is nothing more than mob psychology". The action that they suggest to overcome this does not express confidence in either students or in education; they conclude that "a sociologically 'accurate' description of science may not be what we want to teach students, at least initially" - so much for Portelli's (1993) notion of teaching as an honest, open and cooperative exercise! It is my contention that, within the limitations outlined in section 5.4, it is rational to attend to expert advice in situations concerning scientific matters. This puts some onus on science educators to ensure that the public perception of science is such that expert advice is valued.

The third aim is that children should adopt many of the critical and creative attributes of scientists (giving students the skills to seek and evaluate evidence, and to take part in reasoned debate). Enhancing rationality can be claimed by a number of curriculum areas, not only science but notably history, mathematics and philosophy. However, only science operates in such a direct way with a real, mind-independent world that is reliable, stable and readily accessible. Science education provides ideal opportunities for students to engage in a wide range of investigations and knowledge building activities in which mistakes and wishful thinking are readily exposed. Science education can value creativity but, at the same time, not accept personal theories as an end point. The ability to adjudicate between knowledge claims in ways independent of human desires is a special feature of science that has allowed it to build up a public body of reliable knowledge. Science educators should convey these aspects of science in their teaching.

However, meeting the three aims will not be straight forward. For example, in meeting the first aim and showing science to be fallible, there is potential for conflict with the second aim of advocating a rational trust in expert knowledge. The variation between classrooms precludes any universal solutions to such dilemmas and teachers must face these and work through them on a case by case basis. The theme of dilemmas in teaching is developed in Chapter 9. Teachers should plan specific episodes to meet specific aims and then evaluate the results of their teaching in terms of its contribution towards producing a rational population that would be capable of advancing democratic society.

7.2 Scientific Knowledge

The three aims for science education set in the previous sections are important. However, the immediate goal for science teaching, and indeed its major activity, should be to do with children learning science. I do not advocate returning to science courses that are aimed at producing future scientists, but neither do I wish science education to become a liberal arts course about science. Children need to interact with the real world and develop the understanding and confidence to apply the theories and models of science to the world around them. It is in this way that children will come to learn about science and to gain a rational view of the world. Furthermore, since science education is likely to be in competition with manifold unscientific and antiscientific forces in both formal and informal education, the onus is on science educators to teach in a manner that captures the imagination and reveals to children the fascination of the known and the challenge of the unknown.

Paradoxically, the major problem for science teaching lies in the very success of science. Modern science is a truly amazing human achievement and we should celebrate the knowledge of the world that it has given us. Science is a very creative activity in that those working at the frontiers of science develop and extend their understanding through continually questioning and testing their own ideas and the ideas of other scientists. Science is also authoritative in that it represents the most sophisticated and coherent understanding of the world that we have at any one time. This authoritatve aspect of science has an effect on the field of science education. The very success of science sometimes leads teachers to take pedagogical short cuts, and to teach scientific knowledge in a way that makes it appear as a fixed set of truths. In terms of simply learning the content of science, this is not unreasonable - the structure of the solar system or basic human physiology are unlikely to be challenged at the school level of learning. However, such methods of teaching imply that science is infallible, and the unfortunate outcome of this is that students may develop an attitude of unquestioning belief. This raises two key questions: If scientific knowledge of the world is authoritative, how can we teach it in a manner that is not authoritarian? and How can we represent the creative side of science without suggesting that scientific knowledge is open to challenge by learners?

In answering these questions, we need to distinguish between the authoritarian teaching of science, in which the views of children are devalued and dismissed, and the creative teaching of authoritative science, which is totalitarian only in the sense that the behaviour of the real world is not subject to the whims and wishes of individuals. Somehow we need to get students, who are learning knowledge which is beyond dispute, to be able to experience something of the scientists' creativity in evaluating and critiquing concepts.

One of the factors which contribute to the ability of scientists to be creative is their existing expertise; a scientist working outside the established knowledge base has only a vanishingly small chance of making a contribution to human understanding of the world. The same holds for the teaching and learning of science. It is only by inducting children into the concepts and thinking of science that we empower them to question the understandings that they hold. What this raises for debate is whether induction into science is a method by which rational and effective critical evaluation is encouraged, or whether induction is a form of indoctrination designed to subvert criticism. People who have experienced science teaching that demanded unquestioning belief may be excused for viewing induction as indoctrination - they will have had science presented as a mystical set of preordained knowledge placed above the scrutiny of ordinary people. However, this is not sufficient cause to abandon the scientific approach for the epistemological anarchy of post-modernism. What it should do is to warn us to ensure that induction does not unduly restrain children's thinking and critical faculties.

There are gradations in understandings of any science concept, and even a simplistic understanding does give some grasp of the way the world works. If we acknowledge this, we can induct children into science, and simultaneously encourage them to think critically and creatively. Teachers must present science as authoritative and science knowledge as trustworthy, but they must also emphasise that knowledge exists at various levels of sophistication and 'correctness'. Any science taught should add to the learners' ability to understand and explain phenomena around them, albeit at a level that is unsophisticated when compared with scientists current views. The connection of knowledge to the real world provides a 'reality check' for theories and for understandings held of them. The experiences children have of the world will provide evidence of the inadequacy of some of the ideas and theories that they hold. In this way, children will come to question and challenge their own level of understanding. By this process, students can be successful learners of science and, at the same time, learn about science. Children's knowledge is not at a level at which they can justifiably challenge the foundations of science, but they should know that the processes of questioning and challenging, which occur as scientists match their ideas up against those of others and against the behaviour of the real world, are an important part of science.

There is not a unique 'correct' scientific explanation (although there may be many quite incorrect and unscientific explanations) and a skilled teacher will select a topic and level of sophistication that suits the class and then teach it in an appropriate manner. Children in their early teens may be successful at understanding the quite sophisticated particle model of the melting process. Children aged five are unlikely to cope with the degree of abstraction required to develop an understanding of particles, and to teach this model in a rote-learning mode would be to encourage an 'unquestioning belief' outcome. However, children of five can be given experiences which develop their concept of 'melting' beyond the simplistic notion that 'melting is what happens to ice cubes'. If substances such as cooking oil, honey and chocolate-peanut slab are sealed into plastic bags and placed in the freezer, children can later observe the changes as the bags heat up to room temperature. The range of substances that melt can be further extended if the bags are then placed into containers of hot water. The process of melting can be distinguished from burning by extracting the unmelted peanuts from the chocolate bar and trying to melt them by direct heating. The concept of melting could be further extended by using a soldering iron to melt solder and so include metals in the category of 'things that melt'. In work such as this, children are exploring and extending their ideas in a measured way and avoiding the positivist and postmodernist extremes.

7.3 Scientific Thinking

A measured commitment to a theory does demand an understanding of science, not just of the concepts but of the methods, attitudes and philosophy of scientists. To decribe this as a 'tall order' would be something of an understatement, particularly as we do not advocate that science courses become liberal arts course about science, nor that science courses simply have a bit of philosophy grafted on. Monk and Osborne (1997) have developed suggestions on how history and philosophy can be successfully integrated into content learning in science courses, but a word of caution from Cobern (1996) needs to be sounded here. It is sometimes assumed that understanding the concepts will lead to the appropriate appreciation of science and the subsequent development of students' world view. Against this assumption, Cobern and (in a different context) Kuhn (1993), argue that we need to make the scientific view explicit in our teaching. This is because being able to comprehend the content of science may depend on having an appreciation of the concept of science itself. This has a certain logical appeal to it. Children will only really understand a concept or scientific model if they appreciate the status of scientific knowledge or understand what scientists are attempting to achieve with a particular model. One of the basic complaints that critics have of constructivist teaching is that personal, 'children's science' is developed at the expense of public, 'scientists' science'. That is to say, something fundamental to the nature of science is being neglected. However we must be careful not to imply that, in order sucessfully to learn science, students have to appreciate the ontological, epistemological and metaphysical commitments of modern science. Such a state of affairs would be to reproduce the overly ambitious goals of the STS and the science literacy reformers to which we refered in section 6.2.

In talking of making the scientific view explicit, Cobern goes on to make an important distinction between developing a scientific world view, and developing a world view that is compatible with science. The scientific world view is narrow, and too specialised to be of use to those other than scientists - and, even then, only in their professional work. The second, a science-compatible world view, is much broader and it links better to a world view that might be justifiably developed in general education. Furthermore, the science-compatible world view fits more comfortably with the previously expressed aim of intellectual independence for the non-specialist.

Both intellectual independence and a science-compatible world view imply the need for an understanding of science based on a familiarity with the aims and commitments of science rather than on a detailed knowledge of the intricacies of specific content. Such an understanding would be fostered if students had the ability to empathise with scientists, and be able to think like a scientist. I next consider the teaching of scientific and critical thinking as an essential component of the science education.

Science education can be conceived as a mode of thinking in two ways. The first way involves raising the level of students' epistemological sophistication and getting them to think about the nature of science. For example, Duschl and Gitomer (1991), argue for the need to adopt a more sophisticated epistemology in science education in order that learners develop a 'sense of the rationality of science and the recognition that [knowledge] restructuring is central to scientific development'. In this way, they argue, learners will become capable of 'assessing the degree of legitimate doubt associated with scientific claims'. Such skills would need to be taught explicitly and, although this is a 'philosophical' area, there are programmes available aimed at teaching philosophical thinking to quite young children (for example Cam, 1995). Furthermore, if teachers have in mind the broad goals for science education that I have been advocating, such philosophical outcomes are likely to be reinforced in a concrete manner by the way in which science is taught.

The second way of looking at thinking in science education involves the more general notion of critical thinking, to which authors give different but clearly related emphases. According to Ennis (1991) critical thinking is scientific thinking, and the development of critical thinking forms part of the justification for teaching science. Siegel (1991) conceives of critical thinking as an active 'critical spirit' with which people 'value good reasoning and are disposed to believe, judge and act on its basis'; and this links critical thinking to the wider world view. A connection between critical thinking and the broader sociopolitical goals for science education is made by Weinstein (1991). He argues that critical thinking offers 'a possible mechanism for education for democracy' because teaching of critical thinking helps students to 'focus on their own rational procedures through interactive deliberation... within a supportive community of equals'. This link to social goals is made more firmly by Wirth (1991) who sees the understanding and meaning-making developed through critical thinking as a way of 'retaining our humanity in a fearsomely new post-industrial electronic age'.

Critical thinking is not without its critics. For example, McPeck (1991) and Barrow (1991) criticise critical thinking (cognitive skills) programmes on the grounds that the skills are domain specific and cannot be taught in the abstract. However, even advocates such as Siegel (1991), who argue strongly for the generalisibility of critical thinking skills, acknowledge the need for them to be taught in some context. Others critics, like Rorty (1989), argue that the critical aspect of education should be delayed until learners have received a long period of schooling for socialisation, a suggestion that Hare (1995) rejects as yet another justification for 'authoritarian approaches to teaching'. A more fundamental challenge is made by O'Loughlin (1992). He is critical of the teaching of formal cognitive skills on the grounds that these may increase the child's ability to adapt to present society rather than to criticise or change it. As support, O'Loughlin cites Freire's claims that abstraction is the source of mystification and oppression, (Freire, 1970). The acknowledgement that critical thinking needs to be taught from a concrete base is unlikely to allay O'Loughlin's fears about abstraction. This is because he also embraces the notion that rationality is a cultural construction, and as such has no privileged status as a way of thinking. Claims like O'Loughlin's are characteristic of the post-modern movement which rejects any notion with transcendental or foundational aspect. Such claims rest on the excessive skepticism of postmodernism and we should not take them too seriously. However, as with post-modern critiques of science itself, neither can we afford to be complacent. Weinstein (1991) is supportive of the notion of critical thinking but warns that, while critical thinking is 'characteristically fallibilist and pluralist', it is still foundationalist and open to challenge by radical post-modernists. In a later paper he expands on these challenges to rationality and acknowledges the contribution of Siegel (and Habermas) to the defence of the enlightenment project (Weinstein, 1995). While he refers to critical thinking somewhat cynically as 'resplendent with best-selling textbooks and quick fixes', he maintains that it is important to give it serious consideration. He argues that, 'if Siegel is correct in identifying critical thinking as the educational correlate of reason, [then] getting what reason requires straight becomes the central job of education today, and critical thinking is the terrain of choice'. To strengthen critical thinking against attacks we need to show that can be more than a quick-fix or a passing novelty.

Critical thinking is important in developing both a world view that accommodates science, and in developing a view of scientific knowledge that accords respect but not awe. Further to this, Kuhn (1993) adds a very apposite aspect to scientific or critical thinking. She characterises critical thinking as the gathering and weighing of evidence to support an 'argument', rather than a process involving exploration and problem solving. She also rejects the notion that the spontaneous explorations of children shows them to be 'natural scientists'. For Kuhn, scientific thinking is 'an endpoint...of a complex process of intellectual development', and something that 'does not come naturally but...once you get it you do not lose it'. A rational argument can be constructed either internally as part of our own thinking or externally as part of social interaction. One of those skills needed for this is the ability to distance ourselves from our own beliefs to the extent that we can evaluate them as objects of cognition. An extreme relativist objection might be that such a distancing is impossible, but this would be to deny the existence of any form of sensible social intercourse. To admit that distancing may be possible, but to object none the less on the grounds that we cannot do this absolutely, is to take an excessively positivist view of the world. Rational argument is put in question if people hold absolute and unshakable beliefs, and it is equally in doubt if people are excessively skeptical or hold a totally relativist view of beliefs. Kuhn notes that:

> '[T]he student who says (quoting from one of the adolescents in our argument research), "You can't prove an opinion to be wrong because an opinion is something somebody holds for themselves," lacks any basis for judging the strength of an argument beyond its power to persuade.' [p 335]

The skill of argument is important for rational social interaction but, from Kuhn's research, it is a skill that is poorly developed in many adults. This leads Kuhn to suggest that the relevance of science education might be established by 'connect[ing] the *process* of science to thinking processes that figure in ordinary people's lives' rather than by 'connect[ing] the *content* of science to phenomena familiar in students' everyday lives' [italics in the original]. Kuhn makes two further important points. First, while scientific thinking can be linked to everyday thinking, the two forms of thinking are not the same, a matter which is expanded on by Reif & Larkin (1991). Second, the connection between scientific thinking and thinking in the broader sense must be made, not just in our minds as educators, but also in the minds of our students. This, Kuhn suggests, may best be done by going outside the pure science domain because many students may be inhibited by a feeling of ignorance about science topics. The social science topics used in her research are selected so that 'average people see themselves as competent to hold opinions and make judgments'. Kuhn sees it as paradoxical that 'to enable students to see the significance of scientific thinking we may need to move outside of traditional science domains'. However, I see such a move as essential, not just to see the relevance of scientific thinking but to meet the broader sociopolitical goals for science education. Scientific thinking not only can be, but must be, routinely applied in social contexts, otherwise it will have failed to influence the wider world view, it will have failed to produce a science-compatible world view that is functional. Such a failure would reduce science to being an optional extra within the general education of citizens!

What then can we assemble as outcomes for science education? Learners need to be able to think clearly and critically, and to mount a coherent argument with all that is involved in assembling and weighing evidence. The content and processes covered in science courses must be linked in order that that students will not only learn science but also come to know about science. In this way we build both an understanding of science, and an intellectual independence from it, that is, a view of science based on knowledge, rather than on faith or prejudice. What should we avoid as outcomes of science education? We should avoid getting children to accept what they are told without question or, more to the point, without questioning the epistemic grounding of the knowledge offered. Equally, we should avoid destabilising children's beliefs to such an extent that they believe in nothing, for to doubt everything removes any meaning from what it is to doubt - unless you want to doubt whether meaning exists at all! We should not insult children's intelligence by spoon-feeding them predigested information to be memorised without explanation or application. Neither should we give them an unrealistic faith in any ideas that they may generate, because they may then fail to question their own own ideas, and fail to grow in knowledge. Children should not accept science as the ultimate source of truth, for they may then accept unquestioningly anything labelled 'scientific'. Neither should children be led to see science as yet another passing fad, to be placed alongside tarot card readings and colour therapy.

CHAPTER 8 TRUTH, CULTURE AND SCIENCE EDUCATION

8.1 Science as the Search for Truth

Let me summarise what I have argued so far. In the last four or five decades we have had academic science curricula strongly motivated to produce a continuing supply of scientists; we have had STS and Science Literacy curricula based on 'relevant science' with the goal of helping people live in (and even have some control over) our scientific and technological age; and we have had curricula, based on children's ideas and children's cognitive processes, which are primarily concerned with producing 'conceptual change' in learners. Most curricula also mention learning about science, or learning scientific attitudes, but this is not a major emphasis. For example, the 'Nature of Science' strand has been dropped from the National Curriculum in the United Kingdom, and in New Zealand this strand is significantly under-developed in comparison to the other five strands.

A major goal for science education should be to build in children the capability of critical, analytical, rational thinking (ie scientific thinking). The reason for this is that we will need people capable of applying scientific thinking to the social world in order to make democracy work more effectively. And it will be through having a more genuinely participatory democracy that adequate mechanisms will be found for public input into both the direction of science and the application of technology. A factor that has confounded attempts to define goals for science education has been the development of philosophies of science which either directly challenge the traditional motivations and methods of science, or can be interpreted as doubting the status of scientific knowledge. This philosophical drift is related to a general postmodernist unease about where science/rationality/technology are leading the human race. The unease is legitimate but the solutions, despite the rhetoric of empowerment, are likely to lead to disempowerment and nihilism.

In this chapter I will propose a view of science that maintains its authority but requires us to acknowledge its vulnerability and the limits to that authority. I will also explore facets of science that are useful in developing general principles for science education. I will then examine, in more concrete terms, what these views mean for the classroom and, in Chapter 9, I will present a model for teaching that acknowledges the complexities of the classroom and assigns a vital role to teacher wisdom.

There are two key features of science that I need to develop further. This involves looking first at the behaviour of scientists and second at the goals of science. In turn, this will then require us to revisit the question, What is science?, not in order to settle some long running philosophical debate about the nature of science, but to see what the implications are for science education. First, let us consider the behaviour of scientists. Several decades ago Merton (1942) proposed a set of norms for the conduct of science:

1. Universalism. The validity of scientific knowledge is independent of the personal, social, cultural, and national attributes of the scientist and should be evaluated by cognitive criteria. Careers in science are open to individuals from all cultures.
2. Communism. The products of scientific endeavours belong to the community of scientists. This norm requires open communication within the scientific community.
3. Disinteredness. Scientists are motivated by a desire to extend the domain of human knowledge, without personal interest in particular scientific conclusions. Self-aggrandisement and spurious claims are discouraged. This norm has been cited as responsible for the relative absence of fraud in science.
4. Organised skepticism. Scientists have both a methodological and an institutional mandate to consider only empirically established facts in scientific decision making. This norm requires scientists to suspend judgment until "the facts are at hand".

Along with anyone with a post-positivist view of science, I would require considerable amendment to the fourth norm. However, others (for example Kelly et al.,1993), support the view that all of these norms should be read as an ideology of science, an ideology that serves the interests of the scientific community by enhancing the epistemic status of science knowledge, by increasing scientists' political power and by elevating their social status. But are the Mertonian norms simply shallow ideology? Consider the reverse of the first three norms:

1. Particularity. The validity of scientific knowledge is dependent on the personal, social, cultural, and national attributes of the scientist and should not be evaluated by cognitive criteria.

This may well apply to the world of art, but not science.

2. Isolationism. The products of scientific endeavours belong to the particular scientist. This requires there to be restricted communication among the scientific community.

This may well be a necessary condition for the operation of commercial enterprises under the competitive rules of capitalism, but not for science.

3. Self Interest. Scientists are motivated by personal interest in particular scientific conclusions. Self-aggrandisement and spurious claims are to be expected.

This may bear some resemblance to public relations or advertising activities but not to science.

Of course, any contention that (the first three) Mertonian Norms do describe science is only weakly supported by showing that their inverses do not, but highlighting these counter norms does illustrate where a rejection of them may lead.

Consider the following criteria which, according to Longino, a community must meet in order for consensus to qualify as knowledge:

> 1. There must be publicly recognised forums for the criticism of evidence, of methods, and assumptions about reasoning.
> 2. There must be uptake of criticism. The community must not merely tolerate dissent, but its beliefs and theories must change over time in response to the critical discourse taking place within it.
> 3. There must be publicly recognised standards by reference to which theories, hypotheses, and observational practices are evaluated and by appeal to which criticism is made relevant to the goals of the inquiring community.
> 4. Finally, communities must be characterised by equality of intellectual authority. What consensus exists must be the result not of the exercise of political or economic power, or of the exclusion of dissenting perspective, but a result of critical dialogue in which all relevant perspectives are represented. (Longino 1994, pp144-145) quoted in Duschl & Hamilton (1998) pp1050-1051

Criteria such as these of Longino, or indeed Merton's norms, are important, not because they describe how science operates, but because they are idealisations that provide a set of expectations for scientific behaviour. There are similarities between this idea of an idealisation for science and the idea of a guiding 'myth' for education (Beeby, 1992). Such a myth, or perhaps more accurately such a vision, is a commonly held goal that is distant enough to give guidance and coherence to decision-making without the myth itself having to be continually adjusted. I suggest that the norms of Merton and Longino help to form a vision for the behaviour of scientists. If the norms are accepted as defining how scientists should behave, then individual scientists will consciously attempt to conform to them, and the scientific community will censure anyone who consistently fails to. For example, scientists agree that open communication ought to characterise the conduct of science, but there will be occasions when this does not happen. However, the with-holding of results by individuals will be criticised by their peers; the restrictions imposed for industrial or military reasons will be resisted; and communication between scientists of nations of vastly different political persuasion will occur because scientists' belief in science is stronger than their belief in the politics that keeps other citizens separated. It is important to have this vision overtly presented so that decisions and actions can be challenged on the grounds that they are not consistent with the vision. This is in contrast to Kelly et al., and others of a like mind, who wish to reject science because actions of some scientists are not consistent with the vision for science.

This leads me to the second consideration of this section, the goal of science. For the overall scientific endeavour an appropriate 'myth' is, I suggest, to find the truth about the world. This returns to the important issue of truth which I flagged in Chapter 3 with the quote from Bonnett (1995). On this topic of truth Carson writes:

> 'No one believes anymore that science discovers the truth. Our theories arise from what we have seen, but what we see evidently is influenced by our theories, and by general culture and language that formats our perceptions and imposes structure on the manifold of conceptual possibility. Nevertheless, science is not like any other cultural form - it entails an enormously courageous commitment to keep striving toward truth, however elusive "Truth" may be (Bereiter 1994). Its putative failures are part of the evidence of its continuing success.' Carson (1997) p 234

Science is a source of reliable knowledge not because it always speaks the truth but because it actively seeks to recognise the limits of its theorising. Science is not 'objective' in the sense that the empiricists wish, but scientists work hard to identify all the factors that confound their observations and interpretations. Science is not 'logical' in the sense that Popper wanted, but scientists recognise the need for cogent arguments to be mounted and defended on the basis of the best evidence available. The methods of science evolve (for example, see Worrall, 1999 on double blind testing) and there are changes in metaphysical beliefs (for example about the nature of space and time). This means that any attempt to define science from naturalistic methods (ie by examining how science is or was conducted) will at best be only a partial definition. I suggest that the question 'What is science?' carries with it an unfortunate assumption that science is a finished, logical entity. A more useful question would be 'How is science becoming?'

The issue is not so much with science finding the truth, in the sense of generating knowledge that is certain, it is more to do with the values that science holds. Science is not so much a matter of discovering the truth, but more a matter searching for truth. And truth does lie in a real world that is 'out there' and that is independent of our existence. This is the meaning I take from the Bonnett (1995) quote that, '[G]ood thinking rests in a sense of truth which, far from being essentially 'constructed' by us, is transcendent.' It follows then, that if good thinking is to be a primary aim of science education, and I believe it should be, then a moderate realism will provide better philosophical support than empiricism or even semantic realism. For, unless semantic realism acknowledges that the aim of science is to find the truth, the notion of scientific knowledge as models that can be 'fitted' to the world can be taken as simply an instrumental or pragmatic view. If science education is to teach values, and I believe it should, and if science education is to be worthy of the effort expended by both teachers and students, then the following point is well made;

> "Making sense" of our sensory inputs hardly seems sufficient warrant to maintain the scientific enterprise; and in a science classroom it hardly seems sufficient warrant for the teacher to disturb deeply ingrained and important beliefs of children. Finding out the truth might provide such a warrant.' Matthews (1992) p 305.

8.2 Science as Culture

In discussing the place of science within a liberal education and the content and aims of science education programmes Carson (1997) comments that;

> '[I]n the grand procession of human history, science has played an extraordinary role, impacting deeply upon all the most important and interesting questions humans have ever posed.' p232

and he complains that little of this comes across to the learners. Furthermore Carson says, of the relation between science and society, that;

> '[science is] a profoundly influential cultural force which puts it into complex interaction with other cultural forces, competitive as well as cooperative. It is also, inevitably, a moral and ethical orientation.' p 225.

and, most importantly, that;

> '[B]y distinguishing "science" from "culture", science appeared to be a replacement for culture rather than one of its variations.' p226

Hodson (1998) characterises science education as enculturation and warns of the twin dangers of assimilating and excluding learners. I argued in Chapter 3 that scientific thinking is what defined science, and I will take this a the defining characteristic of scientific culture. Internationally, science is conducted by Indians and Chinese, by Christians and Moslems, by communists and capitalists, and by feminists and male chauvinists. There is nothing inherently Western European or male about science. Although, in science as as currently practised, there may well be extant historical biases (and it may well be that, for example, male prejudice is particularly resistant to extinction). What is of importance is that scientific culture can sit alongside other cultures - thus a scientist can also be a working class, male Jew or a bourgeois, female atheist. Thus, although there will be multicultural science education, where the pedagogy is adapted to suit the background of the learner, there are no multicultural sciences based on different cultures. Put bluntly, there is the culture of modern science and there are other cultural ways of viewing the world. These latter ways of viewing the world are not science and to compare them with modern science is helpful to neither science nor to the other cultures. To avoid the charge of scientism let me hasten to acknowledge the arguments of feminists such as Longino and Harding that a feminist perspective brought to science can improve scientific knowledge by removing biases (see Longino, 1990 for example). However, I take corrections such as these as part of the evolution of modern science rather than as an argument for a separate 'feminist science'.

Scientific thinking does not rely solely on common sense - it is often counter intuitive - and scientific thinking requires an intellectual commitment in order to come to an understanding of the theories and metaphysical beliefs of science. Scientific thinking requires, at times, a willingness to submerge ones ego and submit to the force of evidence and, at other times, scientific thinking requires the courage to stand up for ones ideas against the existence of apparently disconfirming evidence. Scientific culture will clash with any culture that is satisfied with simply making meaning, it will clash with any culture that does not have commitment to finding the truth, and with any culture that does not have a tradition of questioning and critically interrogating ideas. Scientific culture will clash with traditional cultures, particularly those with an oral tradition, and scientific culture will clash with the culture of children. Furthermore, I suggest that many adults in our society live perfectly harmoniously in a meaning-making mode where, in the workplace, in the home, and with friends, most conversations are designed to retell stories and maintain social relationships rather than to seriously question anything. Thus scientific culture will also clash with the culture of many adults.

Cobern (2000) mounts an interesting argument for science education to acknowledge the presuppositions of science and to remove the distinction between belief and knowledge. I have no objection to these proposals because Cobern is arguing against '[t]he anti metaphysical project of positivism [that] sought to make science a self contained rational endeavour'. The metaphysical underpinnings of science need to be made transparent but, despite Cobern's eschewing of an 'anything goes' attitude, I have misgivings about his notion of plurality and the claim that there can be no privileged stance on what presuppositions are necessary to science - this is too close to a relativist position. Some beliefs, for example the Maori belief in the spiritual link between people and land, are simply incompatible with modern science, but this is not to say that one cannot be a Maori and a scientist. Furthermore, it is not to say that science education should try to eliminate the belief in spirituality, nor that science should be prepared to accommodate some sort of spiritual dimension - the two different views will simply coexist within the two cultural systems and will be used in appropriate cultural contexts. The examples that Cobern does give of clashing presuppositions are typical of 'boundary setting' that has been discussed in section 5.4, and I see no reason to make contestable any fundamental metaphysical beliefs of modern science.

The above arguments about the nature of science would not be of crucial importance if leaning of scientific concepts was all that was at stake. However, as I have indicated, adoption of scientific thinking is a key goal of science education and this is all too easy to subvert. Stinner and Williams (1998) are anxious to avoid the influence of postmodernists and radical constructivists and suggest a way of overcoming the public disenchantment with science. Their proposal is for a 'Science for Everyone' (SFE) that is not only for everyone but perceived to be so. They give four principles for SFE. The fourth principle relies on basing science education on 'sound scientific principles' which, they claim, have 'made great strides in recent years'; this is in direct conflict with Chinn and Brewer (1998) quoted in section 6.1. What of the other three principles? The first principle is that science should be comprehensible for most students and to ensure this there will be a core of essential material that 'does not make intellectual demands on students that are beyond their capacity'. The second principle is that science should be meaningful; students are to be able to 'make sense out of the natural phenomena that they experience in their daily lives and to solve their real life problems. The third principle is that science is to reflect the nature of science by providing a human face to science and presenting science as 'an eclectic and creative process of search and discovery'. I hold two reservations about these principles, first, they suffer from the problems of STS and science literacy claims (see section 6.2) and second, the principles clearly accept that science education has the limiting goal of 'learning in science'. In addition, I find that these principles smack of 'dumbing down' the science in order to meet perceived inadequacies in children, rather than getting children to meet the challenge of understanding science.

Getting children to meet the challenge of learning science does require considerable pedagogical skill and this is the subject of the next section. However, even with the most skilled and the most motivating teacher, learning science is never going to be easy. Children in all cultures (including ours) experience some form of 'rites of passage', a cultural induction to the ways of adulthood. For many children, this consists largely of learning the protocol of adult 'tribal' life for example passing comments about the weather, or discussing sport. In these settings, most conversations are 'meaningless' unless they are seen as 'story-telling' designed to reinforce the social fabric. An example of induction to the culture of work is given in Willis (1978). In contrast to 'rites of passage', induction into scientific thinking is to move children from thinking tribally to thinking globally, to raise rationality to a new level and with it the level of ethical thinking. Scientific thinking is not to replace tribal story-telling, this is still required for social cohesion, scientific thinking is to lie alongside meaning-making and to add a new level of choice to children's actions The move from meaning-making to scientific thinking is unlikely to occur naturally, nor is it likely to occur by just letting children explore, nor even by getting children to mount 'arguments' on the basis of their own ideas and experiences - children's science is simply not science. Considerable intellectual effort is needed in order that learning in science and learning about science lead children to an understanding of science and to the skills of scientific thinking. This is the reason why learning science must be worth the effort, this is why anything less than moderate realism's commitment to truth is unacceptable.

We need to raise the level of rational thinking and with this the level of ethical thinking in order to cope with the complexity of modernity, in order to build a better society, and to in order to become more reflective about science itself. We cannot disestablish science as the postmodernists might wish, but we may be able to rationally and democratically question what sort of knowledge we need, where science research should head, and so on. Opponents of science and technology are not irrational, they are looking for a solution to the inhumanity of science and technology, they are looking for some way of closing the Pandora's box that was opened half a millennium ago - they are muddled in their analysis, but sincere in their intent. Science and technology do not need to order people in the ways that so concern critics such as Heidegger (1997: 1949). The concerns raised are real, but any solution that denies science is unrealistic and will end up disempowering the very people it purports to help - there is no post-modern solution. Not all critics seek to denigrate science, Feyerabend (1980) looks for a return of science to a non-ideological, liberating force, and Toulmin (1990) sees the solution lying in combining Renaissance humanism with modern rationality. Modernity is not about technology but about a way of thinking, it is not that modernity has overtaken people but that the thinking of a majority of people needs to catch up with modernity. Scientific rationality must be a mode of thinking available to all people and a mode of thinking that gives additional choices to people so that society might then be more reflective and truly democratic. It is not so much that we need to graft Renaissance humanism onto society, but that we need a new, robust form of humanism that is an integral part of a rational modernity, a humanism that will ensure that the culture of science works for humanity and not the reverse. It is to this goal that science education must contribute.

8.3 Science in Science Education?

Science educators often paint science as an 'every day activity' and a 'human invention' in order to provide a 'science for all' and a pedagogy that teaches science humanely.

These are commendable goals but we must be careful not to make science out as something that can exist at a meaning-making level, and we must be careful not to understate the intellectual endeavour involved in learning science. Even as a pedagogical strategy, such views are dangerous. Teachers without scientific expertise may believe that 'talking about the needs of pets' represents sufficient intellectual commitment to be learning science, and teachers with scientific expertise may believe that attending to lessons and carrying out laboratory exercises represents sufficient intellectual commitment to be learning science. In neither of these situatuations will the teacher be promoting scientific thinking. Over the last few decades science education has been concerned with conceptual change and, this does involve a deeper commitment for both teacher and student. But science education is both more than conceptual change and less than conceptual change. Science education is more than this because changing the concepts in itself is insufficient. What is required as well is a change in thinking, the development of a rational, scientific way of viewing the world. Science education is also less than conceptual change because there are few, if any, concepts that are crucial to running our lives, and because we are not seeking to convert children to scientific thinking but simply to add this to their other ways of viewing the world.

In order to characterise science for the classroom, I suggest that the following questions are significantly asked in science:

> I wonder what would happen if...?
> Why does this happen?
> In what other ways could I explain this?
> Which is the best way of explaining this?
> Why do I believe that is the best way?

These question could be used as a framework for children's own investigations, because children need to get a feel for 'doing science'. However, more importantly, these questions should be used as a framework for studying existing scientific knowledge, because it is the concept of science that we are trying to teach, not the scientific concepts themselves. Scientists 'do science' by using scientific thinking to generate science knowledge and children 'learn science' by coming to understand scientific knowledge, and thus developing scientific thinking.

It is a truism that students must construct their own knowledge but I reject the narrow constructivist notions of learning as personal construction. I endorse the broader notion of learning as public construction of knowledge, and also support the notion of scaffolding and the use of 'existing knowledge' as an essential component in the construction process. This casts the teacher in a much more proactive role in the classroom while not diminishing the need for pupil participation. The classroom should be seen as a learning community or even a knowledge generating community, but we must be careful when comparing this with the scientific community. For example of Longino's four criteria for a knowledge producing community, the three concerned with standards and uptake of criticism would translate quite easily into the classroom. However, the fourth criteria that requires equal intellectual authority must be treated with caution. It would be simply deceitful to pretend that learners, the teacher and established science knowledge (as embodied in texts for example) are of equal intellectual authority. Scientific knowledge is authoritative (and presumably, to varying degrees, so is the teacher). Having said that, and before I bring down the liberal wrath on my head, let me also emphasis that it is important not to teach science in an authoritarian manner. Some traditional science teaching could reasonably be criticised as being ideological - what a skilled science teacher does is to induct children into science without indoctrinating them. Ideology is characterised by muddled thinking, unconsidered actions, and inflexible decision-making based on tradition; indoctrination into science gives no grounds for criticism an leads to disempowerment. Rationality is characterised by clear thinking, considered action and decision-making that is revisable based on further critical evaluation; induction into science teaches grounds for criticism and leads to empowerment. Teaching that leads only to meaning-making, or to relativist views of science, does not set out to actively prevent criticism, but it subtly denies the possibility by removing the grounds for critical analysis; because of its covert effects, this teaching is more dangerous than overt indoctrination.

It is clear that we need to avoid indoctrination into science, it is not as clear exactly what induction into science entails. The use of analytical and critical faculties in the scientific community presupposes a high level of background knowledge. How could children use analytical and critical skills in the classroom if existing scientific knowledge is authoritative? And how do children gain these analytical and critical skills in the first place? In answering the first question, I hold that, the occasional child prodigy excepted, children will never be in the possession of sufficient knowledge to seriously critique existing scientific knowledge - this is not scientism but simply an honest assessment. Children should be taught in a manner such that they see their own knowledge as something that is occasionally revised and becomes progressively more sophisticated and inter linked. A key to this is the notion of having a 'measured commitment' to a theory. By this I mean that children will have developed a 'theory' in which they have a 'measured' belief - that is they have measured the theory against observations, other vicarious evidence, and rival theories. Children will have a 'commitment' to the theory in that they will expect the theory to explain new observations, be consistent with new evidence, and be better than any new theory. If Ohlsson (1999) is correct, then having this sort of commitment should highlight the 'anomalous' nature of any counter evidence, and so enhance the chances of children questioning the theories that they hold. Children will question either the depth or the extent of their own theories and understandings, but this still leaves the question of how will they judge 'when to hold and when to fold?'. At this point I suggest that the difference between doing science and learning science becomes clear. Children do recognise that there are authoritative sources that they can consult, and teachers should not shrink from being one of these sources. I am not advocating that teachers simply 'tell' children what to think, nor, I suspect, would many teachers want to do this. What I am advocating is that teachers (sometimes) set children the task of identifying the ways in which a theory or explanation that the teacher presents is better than that held by the children. Even, and perhaps especially, if the presented theory is counter-intuitive, teachers will need to have established a climate in which children readily accept that the theory is 'better' in certain aspects. The teachers' task is then to motivate children in the task of identifying the ways in which it is better. In this way learners can practice the scientific thinking of scientists engaged in knowledge production without the nonsensical pretence that established scientific knowledge is able to be challenged and revised by learners.

The question of how scientific thinking develops in learners can be answered by looking at the development of science itself. I argued in Chapter 3 that, along with certain metaphysical beliefs, social and economic conditions, and the existing meaning-making trait, the community of modern science arose from a high level of critical reflection and the active pursuit of evidence through experiments. Furthermore, science contains a positive feedback mechanism whereby initial advances brought about a snowball of further advances. We should be able to make use of the same feedback mechanism in science education - once you understand a bit about science then it becomes easier to learn more. If this is so then a teacher's key role is to 'prime the pump'. Teachers could use the five significant questions outline previously as a framework for presenting the ideas of science and for children's own investigations. A further implication is that the earlier this starts the better. Whether ideas are children's own, informally developed ones, or whether the ideas are derived from a more formal study of standard scientific knowledge (of an appropriate level of sophistication) the earlier we can get children seeking evidence for ideas the better.

The questions now are, 'What does this mean for specific programmes in specific classrooms?' and 'How does a teacher set up the correct classroom climate?' The answer to these and similar question is, 'It depends'. And it depends on so many factors that the usual curricula, wherein particular content is specified or particular methods are prescribed, are almost bound to fail. In the next chapter I will develop an alternative, much more open ended approach.

CHAPTER 9 TEACHING DECISIONS IN SCIENCE EDUCATION

9.1 Questions of What and How to Teach

In Chapters 6, 7 and 8, I have moved from a broad rationale for science education to three general aims and then to a more detailed look at how aspects of scientific content and thinking could be structured to meet these aims. However, there are good reasons why it would be presumptuous to try to prescribe what and how teachers should teach.

I start with an analogy. A London bus driver, a New York cabby and a Beijing cyclist all make the production of order from chaos look deceptively easy. Each of them is required to continually make decisions based on a myriad of incoming data. There are general traffic rules operating, but the quality of the decisions made is dependent on professional judgment and 'local knowledge'. Teachers operate in a situation with a similar of high data-flow and, like drivers, teachers must be allowed to exercise professional autonomy within some well defined constraints.

More so than drivers, teachers have difficult decisions to make, and with fewer guide lines. Research in science education has produced a number of important insights and developments. For example, current teaching methods are influenced by the recognition that children's preexisting ideas affect learning. However, while these 'constructivist' teaching methods have merit, they do not provide the ultimate answers to teaching questions (Osborne, 1996). Similarly, research into the characteristics of a successful teacher has provided disappointing results, even if the search has not been entirely fruitless (Brophy & Good 1986). So, when conducting pre-service or in-service teacher training in science, can we provide a mature and comprehensive educational theory on which teachers can base decisions? Clearly the answer is no. To return to our driver analogy, one might say that there are a few tracks rather than clear roads, there are arguments over which of these to take, and arguments about the nature of the destination. And, to push our analogy even further, some drivers feel that their passengers are at best apathetic about the journey or, at worst, openly hostile.

A feature that makes teaching into a complex activity is the need to continually resolve tensions. These tensions arise in at least three areas; in the relationships between teachers and learners, in the process of selecting which knowledge and skills to be taught, and in the interactions between education and the many facets of society. For a comprehensive theory on how to resolve these tensions, there are many questions that we would need to answer including:

- first, about learning,

  How do human brains recognise patterns in data?
  How do children develop abstract concepts?
  Is learning limited by maturation or is maturation enhanced by learning?
  Are education and entertainment complementary or contradictory concepts?

- second, about teaching,

  Do teachers have some authority to teach, and if so from what is this derived?
  Who or what provides the motivation to learn?
  Are teachers curriculum developers or followers?
  Are teachers sources of knowledge or facilitators who learn along with the children?
  Why do we have schools at all?

- third, about science,

  What is the scientific enterprise about and how does it operate?
  What is the status of modern scientific knowledge? For example, does matter have a particulate nature or is this just a convenient metaphor?
  What are we to make of concepts such as truth and objectivity?

- fourth, about science education,

  Why do we insist on teaching science to children?
  What are the most important science concepts and when can they be taught?
  How and when do children best learn science and how is it best taught?
  Is scientific thinking just enhanced everyday thinking or something different?
  How accessible is the scientific world view and what enhances and what blocks its adoption?

- and finally, about society,

  What influences the course of human history?
  Are there transcendental principles influencing human behaviour?
  Who benefits from modern science?
  Where is human society heading?
  What is 'the good life' and how can we achieve it?
  Do we have 'democracy', and if not what might 'real democracy' look like?

What complicates education even further is that when, or if, we get answers to these questions, we must keep in mind the distinction between what is and what ought to be

(Carr, 1995). We may find, for example, that middle-class children are better at abstract thinking than working-class children, but is this an unalterable biological fact or a cultural artifact that needs redressing?

Some of these questions about society, science and education were raised in earlier sections. The questions of immediate concern are: How can we teach confidently in the face of uncertainties? and How can research help in this?

9.2 Dilemmas in Teaching

I would not presume to prescribe how to achieve the outcomes for science education that are outlined in Chapter 5. There are two main reasons for this reluctance. First, educational theory is not at the level that it can offer unambiguous guidance. Successful education is still a matter for the creative and critical combination of teachers' craft skills and local knowledge. Only the teacher knows which of the children's other curriculum experiences and knowledge science can be linked to; what it is that interests and motivates their students; what level of challenge their students respond to; what level of practical skill the class has developed; what attitudes towards learning and towards science their students bring from home; what school and community resources are available to support the science programme; what the level of cooperative skill is in the class; and what the immediate and longer term distractions are (such as the weather and forthcoming swimming sports). Second, there are often conflicting demands on teachers which are not amenable to a single resolution because some questions may, in principle, have no definitive answer. For example, should teachers help particular children to cope by making an adjustment to the task asked of them or should teachers help children face the challenge by insisting that they meet the criteria set? To assist teachers to consider and consciously react to sets of competing demands, I introduce the notion of 'dilemmas' (Berlak & Berlak, 1981).

Some recent papers have taken a superficial view of dilemmas as problems that are met by beginning teachers, and to some extent resolved by them, (Tomanek, 1994; Volkman & Anderson, 1998). In contrast, Berlak & Berlak view a dilemma as a fundamental tension between two opposing demands. I have adapted from Berlak & Berlak (1981) and Suppes (1995) a list of dilemmas (by no means exhaustive) and loosely classified them as applying to schooling in general or to the content and method of science education in particular.

Dilemmas for schooling in general, involve decisions regarding:

intrinsic motivation
versus extrinsic motivation

learning as social
versus learning as individual

learning as holistic
versus learning as molecular

teacher as involved human being
versus teacher as objective professional

children treated according to needs
versus children treated equally

individual freedom
versus the discipline of the group

In deciding what to teach, there are dilemmas for the teacher relating to:

teaching through an applied science topic
versus teaching through a pure science topic

selecting the descriptive aspects of a topic
versus selecting the theoretical aspects of a topic

emphasising the processes science
versus emphasising the content knowledge of science

presenting science as problem solving
versus presenting science that involves searching for the truth

In deciding how to teach, there are dilemmas for the teacher relating to:

being a fellow learner
versus being an authoritative source of knowledge

approaching knowledge as contestable
versus approaching knowledge as a given that must be comprehended

involving students in first hand explorations
versus involving students in formal laboratory exercises

basing lessons on the generation of knowledge
versus basing lessons on the confirmation of knowledge

Such conflicting pressures are by no means restricted to education. For example, our lives involve a tension between free will and determinism, that is, between our position as a conscious individual and our position as a product of an all-encompassing set of social forces. We do not 'resolve' this by exerting our free will nor do we submit to being a total pawn of fate. Instead we live out our lives in a constant interplay between these two extremes which, in the view of Marxist dialectics, is a state of affairs that is natural and inevitable, rather than contradictory and resolvable. Consider again our previous dilemma of whether the teacher should adapt the task to the child or the child to the task. Clearly there are no universal or final resolutions to such a dilemma, and teachers will continue to meet such situations and be forced to respond to them on a case by case basis.

At our present level of pedagogical knowledge, teaching remains as much an art as a science but, like science itself, educational theory is still developing. Research on such diverse topics as 'Family Science Nights' (McDonald, 1997) or the operation of the brain (Anderson, 1997) will continue to provide further insights, and may eventually produce coherent theories of teaching and learning. In the meantime, while some research may promise better knowledge and theories tomorrow, teachers must continue to operate today. It is for this reason that we develop a model that provides an educationally defensible 'destination', empowers teachers to exercise their professional autonomy in selecting the 'route' and provides a coherent framework for research that will improve both.

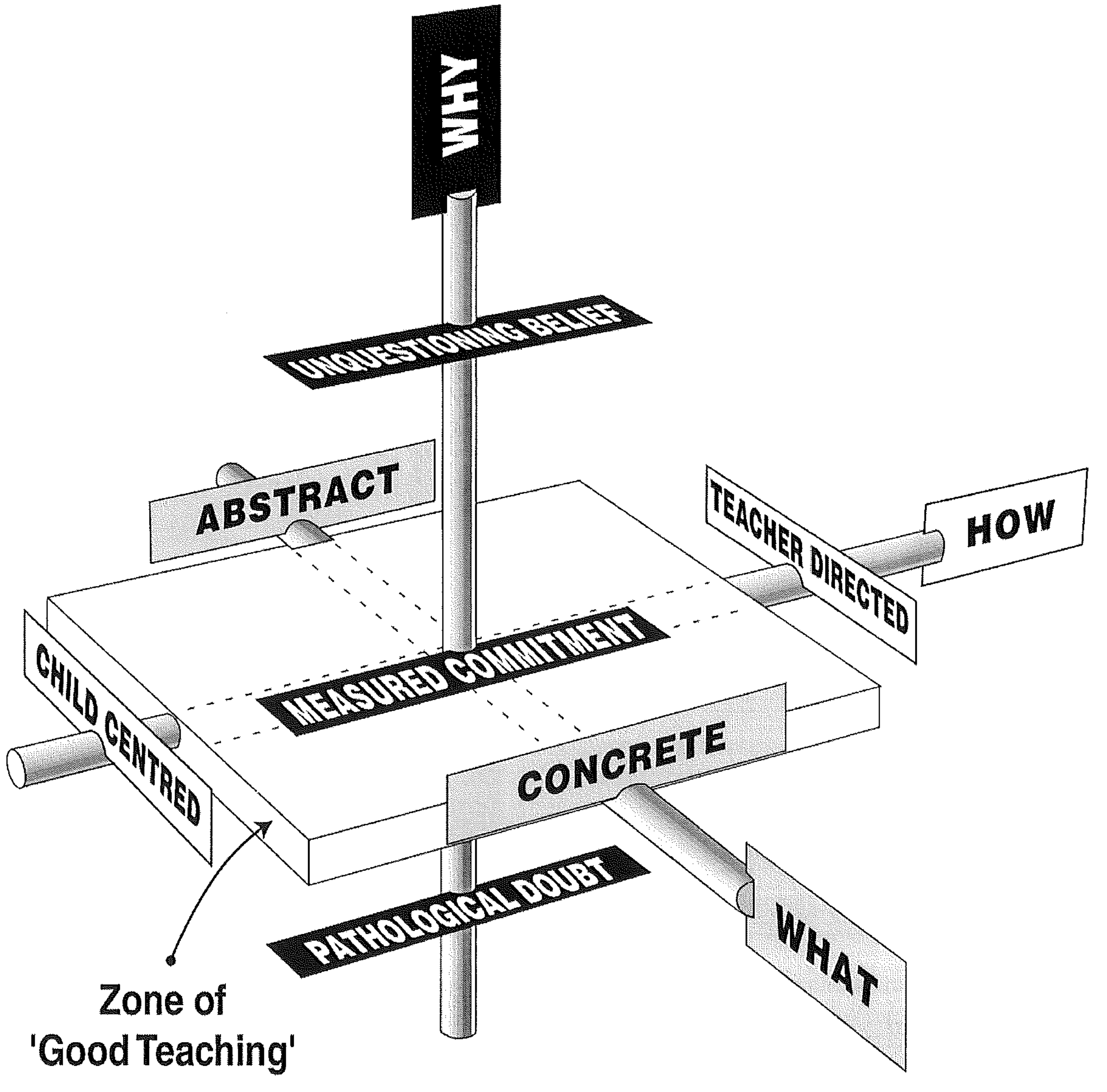

Figure 2 A model for evaluating science teaching

Teaching episodes are classified according to the content that is selected, the teaching method used and to the outcome that these produce in learners.

The zone of good teaching lies close to the horizontal mid-plane in which the outcome for learners is the development of a measured commitment in science

9.3 A Model Based on Teacher Autonomy

In the model shown in figure 2, teaching episodes are classified by the three characteristics; what is taught, how it is taught, and the reason that it is taught. The teaching episodes are then represented in the model as points in three dimensional space where 'Why' is the vertical dimension, and 'What and 'How' are the two horizontal dimensions. I have used, from section 5.2, Norris' ideas of 'unquestioning belief' and 'pathological doubt' (Norris, 1997) to mark the two extremes on the 'Why' axis. These extremes must be avoided, and we must aim instead at the central 'balance point'. This point on the outcome axis is a 'measured commitment' to theories, that is to say, a theoretical commitment that is relatively stable but is revisable on the basis of further evidence or a better theory. An explanation for the labels on the What and How axes is given below. Broadly speaking, teachers are free to make whatever content and method decisions they see fit, providing the decisions are ethically defensible, and providing that the decisions lead to the general goal of 'measured commitment'. Thus, in terms of the model, a teaching episode is 'good' if lies close to the central plane, and increasingly questionable as it moves above or below this central plane.

In section 7.2, I suggested four dilemmas that may influence decisions on the what is to be taught. These dilemmas were concerned with:

teaching through an applied science topic
versus teaching through a pure science topic

selecting the descriptive aspects of a topic
versus selecting the theoretical aspects of a topic

emphasising the processes science
versus emphasising the content knowledge of science

presenting science as problem solving
versus presenting science that involves searching for the truth

In reacting to any one of these dilemmas, the decision made will be influenced by other decisions on what to teach, by decisions made on how to teach and by decisions made on general educational matters. Furthermore, the effect is reversible and as soon as any one decision is made it may alter a teacher's judgement of the appropriateness of other dilemma decisions. In the model (figure 2), decisions on what to teach should themselves should be located in multidimensional space. However, the point of the model is not to provide researchers and curriculum developers with a comprehensive analysis of classroom decision-making, and it is certainly not to define courses of action for teachers. The point of the model is first to provide teachers with a clear goal for science teaching, and second to provide a simple framework from which teachers can make decisions, about what to teach and how to teach it, based on the best evidence at the time.

There is one problem with collapsing all decisions about what to teach into one dimension, and that is to find useful labels for the axis extremes. On the left hand end of each of the dilemma descriptions lies lesson material which is applied, descriptive, that emphasises process and that involves problem solving. Lesson content with these characteristics is likely to have been chosen because it is primarily 'concrete' in nature, and this end of the axis has been labelled accordingly. The alternative is content that is presented within a pure science topic, covers theoretical aspects, emphasises content over process, and involves the notion of truth. Under such circumstances I suggest that the content selected is likely to be primarily 'abstract', and this forms the second label. Two points must be made at this stage. First, I do not mean to imply that responses to the four dilemmas are necessarily linked in the two combinations given above. Clearly, selection of particular topics could lead to theoretical aspects within an applied topic, or process could be emphasised within a pure science topic. Second, unlike the 'Why' axis, there is not a central or preferred lesson content to be aimed for, and neither is there any that must be avoided. The goal of developing a measured commitment does not exert an *a priori* exclusion on what to teach. Each dilemma in this area is reacted to for a particular class or particular child under particular circumstances.

In section 7.2, the dilemmas associated with decisions on how to teach were:

being a fellow learner
versus being an authoritative source of knowledge

approaching knowledge as contestable
versus approaching knowledge as a given that must be comprehended

involving students in first hand explorations
versus involving students in formal laboratory exercises

basing lessons on the generation of knowledge
versus basing lessons on the confirmation of knowledge

How to teach is similar to What to teach in that it should really be defined in multidimensional space, rather than being represented by a single dimension. On the left hand end of the dilemma descriptions are methods where the teacher is a fellow learner, knowledge is contestable, there is first-hand exploration of a topic and the emphasis is on generating knowledge. Such a combination would be likely to be 'child centred' and I use this as the appropriate marker. Alternatively we have 'teacher directed method' which relates to decisions where the teacher is an authority, knowledge is taken as given, and there is formal laboratory work related to the confirmation of knowledge. As with the content dimension, the four 'How' dilemmas are not necessarily linked in the combinations given above, and neither is there is any central or desired method. The goal of developing measured commitment does not exert an *a priori* exclusion on how to teach, nor does it privilege any particular method of teaching. Each teaching decision made in response to dilemmas on how to teach is made for a particular class under particular circumstances, and must also take into account the particular decisions made on what to teach. It is the combination of what to teach, and how to teach it, that should contribute to the outcome of a measured commitment. I would like to restate here that the purpose of the model is to emphasise to teachers as clearly as possible that topics and methods cannot, in isolation, be judged 'good or bad'. And to demonstrate that 'good teaching' is represented by all of that zone in the model which leads to the outcome of 'measured commitment'.

Although teachers will make autonomous decisions based on local knowledge, I do not want my model to give the impression that all teaching decisions are idiosyncratic, pragmatic and beyond general guiding principles. Nor, indeed, I am advocating any dramatic changes in science teaching. If science education has a common goal then, allowing for local conditions, all teachers are likely to make similar decisions. These decisions are also likely to have much in common with the decisions now made within the best of current practice. Take, for example, decisions about the general topics to be studied in science. Currently, topics are fairly predictable; few courses would not at some stage introduce students to electric circuits, dissolving, and the structure and function of plants. There may be variations in the timing, the emphasis or, most recently, the context in which these topics are introduced and studied, but it would be an unusual course that avoided these subjects. This would continue to be true because my model specifies the rationale for selecting topics, rather than exerting any direct influence on the choice of topics themselves. I note here that STS reforms have exerted some pressure to move to real-life or 'relevant' science and that this introduces difficulties because of the inherent complexity of such topics. However, if we take up Kuhn's suggestion from section 6.2 and align relevance with process rather than content, we remove the pressure to focus on the relevant but rather messy 'everyday science' topics.

A high degree of autonomy for teachers has been advocated, not because this is necessarily a good thing in itself, but so that teachers make conscious decisions on what and how to teach. The outcomes of teaching must be continually and consciously monitored because we cannot rely on judging the content and method decisions as 'good' or 'bad' in their own right. A 'traditional' examination course in science may contain content that is largely abstract, and it may be taught in a teacher-directed manner. Some learners may find the subject difficult and sometimes be bored but, while this is not 'good' science teaching, it will not necessarily lead to undesirable outcomes. Students may work hard to gain an understanding and a 'measured commitment'. On the other hand, if the teacher is so worried about 'getting through the syllabus' that not only is the majority of the course abstract and teacher-directed but students are also coached in answering questions without any real understanding, then there is a real danger of developing an attitude of unquestioning belief (or simple rote learning!). In contrast, there are good educational justifications for making science interesting and relevant by dealing with everyday topics and by capturing the children's imagination through creative teaching methods. However, if so much emphasis is placed on both child-relevant content and child-centred method that the teacher over-emphasises the generation of personal ideas and loses sight of the pool of public knowledge that enables us to understand the world, then there is a danger of moving towards relativism, doubt and the devaluation of science. The point of the model is to alert teachers to the reasons why they are teaching science, and to encourage them to evaluate the learning outcomes in terms of their contribution to meeting the overall science education goal.

The reason for advocating autonomy in the model is so that teachers can develop a clear rationale for any particular bit of science they are teaching. For example, laboratory work has been criticised as having being applied without much thought to its purpose (Hodson, 1988; Osborne, 1993). 'Pracs' have often been assumed to be motivational, to teach laboratory techniques and investigative skills, while at the same time giving concrete experience of new or abstract concepts. In reality much 'lab work' probably does none of these things very well, and is considered by many students a pleasant social interlude and a welcome break from taking notes. At a different level, investigation of a thick corn flour paste (which behaves in a peculiar and fascinating manner when it is stirred or left to sit) has been used with preschool children for language enhancement and the development of observation and other process skills (Fleer and Hardy, 1996). Teachers could also use the paste to illustrate the idea that not all systems can be simply explained; the children would be asked to speculate on the observed behaviour of the paste without any intention on the teacher's part of judging the value of the suggestions made, or of providing a publicly accepted explanation. Alternatively, children may be allowed to freely explore the behaviour of this paste as a purely motivational activity with no follow-up intended. Each of these activities - whether developing skills, illustrating complexity or simply allowing children to have fun - could be judged as making a useful contribution to the overall goal of science education, providing the activities were consciously structured as part of a balanced science programme.

So far the model may appear unsatisfactory in that it gives little concrete guidance to teachers. Unfortunately, I believe this to be inevitable. There is a problem with any curricula which specify content, method or both, without allowing for the myriad of variables which daily affect each classroom. Such curricula risk producing poor teaching and ineffective learning because the teachers have great difficulty meeting the curricula requirements. I believe that a curriculum could be built around my model (although this is not a task I will be attempting in this thesis). Such a curriculum would need a minimum of three sections. The first section would be a discussion of the background themes of this thesis (the nature of science, the nature of society and their inter-relationship) pitched at an appropriate level. The second section would give suggested science topics and, rather than giving lists of content, for each topic there would be examples of scientific theories that might be held at different levels. The third section would contain, for each topic, examples of teaching units that have actually been tried and evaluated, and examples of methods used to teach the topics (with teacher evaluations of their effectiveness). Most primary teachers have enthusiasm and wisdom, and a desire to do well by their students. Most primary teachers lack both the time to collect resources and the scientific expertise to evaluate them. All primary teachers could evaluate, adapt and use resources in the form of pre-trialled teaching materials (particularly when there is no demand to replicate what is in the materials). The materials would need to cover the full range of 'teaching' shown in the model - from teacher-directed presentation of theoretical content to, child-centred approaches using concrete content. I believe that the curriculum material should consciously avoid promoting any particular topic or method. In terms of what and how to teach, I am a thorough-going pragmatic, eclectic, relativist! - this really is an area where 'anything goes' (providing, of course, the teaching outcomes lead towards the overall goal.)

The exercise of autonomy precludes the notion of a curriculum that prescribes what and how to teach, but it does not preclude the existence of general guide lines to good practice nor the ability of researchers to enquire into teaching and learning and so enhance teachers' wisdom. How can we advance our knowledge of science teaching? How can researchers best help teachers? It is to these questions I now turn.

CHAPTER 10 ADVANCEMENT IN SCIENCE EDUCATION

10.1 Paradigms and Progress?

Perhaps the most consistent feature of science education reforms is that they gain many disciples and fail to live up to what was expected of them. We need to identify the problem with such approaches and find a different way of improving science teaching.

In a comprehensive examination of the reform needs in teacher education Dana, Campbell & Lunetta (1997) see the failure of previous reforms as the result of inappropriate 'top down' development models by curriculum 'experts', and lack of ongoing support for teachers. In order to make intelligent teaching decisions, teachers need to understand what a reform is trying to achieve and, for this reason, Dana et al. reject both 'bags of tricks' approaches and the production of 'teacher proof' materials as ways of promoting change. Marx, Blumenfeld, Krajcik & Soloway (1997) reach similar conclusions in their very detailed analysis of the adoption of project-based science. One of the numerous documented problems in getting this approach to science teaching implemented was that teachers would adopt partial strategies in order to meet particular challenges, rather than adopt the approach as a whole. However, I would question what the key feature is here; is it the 'new method' itself or the outcomes that it is supposed to produce? It is an error to focus teachers too narrowly on the new method (or new content), for the extent to which these are adopted then becomes the criterion by which teacher success is judged. The priority accorded to the new content or new method becomes the driving force and this distorts teachers' decision making processes. Schemes from the past, such as the Nuffield science courses or PSSC physics, provided excellent teaching resources. However, these resources tended to prescribe content and/or method, and these constraints made it difficult for teachers to respond to the full range of daily dilemmas and to meet the outcomes demanded. Currently, a constructivist curriculum that places heavy emphasis on interactive teaching method will automatically impose constraints to the way in which teachers can respond to content dilemmas and this is likely to limit the outcomes that can be achieved. In terms of the teaching model in this thesis, any prescription placed on content or method will restrict access to the full 'zone of good teaching'.

Both sets of authors, Dana et al. and Marx et al., stress the need for a total approach to curriculum development and they reinforce the notion that curriculum development is also teacher development. According to Dana et al., teachers need understandings of 'themselves; their students; human development and diversity; subject matter; educational theory; curricular design; instructional methods; federal, state and institutional regulations; and political, social and moral relations between education, the community, and the world at large'. As an ideal, there is little fault with such a list, and I certainly support the case made for 'lifelong learning', for a supportive 'professional community', and for self-learning from 'reflective practice'. However, I find it difficult to accept Dana et al.'s notion of the need for, or existence of, a 'paradigm shift' in teacher development. Such a notion implies a final 'solution' to dilemmas or a 'new way' of doing things, and this simplistic approach leads to the sort of single-dimensional 'reform solution' that has failed in the past. A more fundamental objection to the notion of paradigm shifts in educational research is raised by Lakomski (1992). She points to the strong relativist implications in claims that are sometimes made for the incommensurability of different paradigms. There is more than one way to skin a cat, but equally importantly, it is possible to agree that the cat has been skinned and, with some argument, to judge which was the more effective manner of skinning. We do have standards of adjudication, and in science education it should be possible to judge, for example, which programs give students the maximum intellectual independence.

Thus, while I have sympathy for many of the ideas of Dana et al. and Marx et al., particularly those related to the need for reflective practice and for teacher collaboration in a collegial atmosphere, there are better ways of influencing practice than through the implementation of 'new' schemes or theories in the form of 'paradigm shifts'. In the next section a case is made for informing teachers through a type of cooperative research.

10.2 Research and Reform

In section 7.1, the problem of distinguishing 'what is' from 'what ought to be' was raised using the hypothetical issue of the differential achievement of middle class and working class children; should this be taken to reveal a biological given or a social artifact that needed addressing? Based on the same general is-ought problem, Carr (1995) raises a fundamental (but not necessarily fatal) dilemma in the relationship between theory and practice. He expresses the dilemma as follows:

> 'If the professional understanding of teachers is to be regarded as informed by the outcomes of certain kinds of quasi-scientific empirical observation and experiment then there would appear to be little to prevent the collapse of practical reason into the technicism of applied science. On the

other hand, however, if we insist that the scientific findings of action and other educational research do not determine educational conduct in any technological way but are liable to be influenced, even rendered irrelevant, by moral and evaluative considerations, then we are back to observing Aristotle's clear distinction of Phronesis from both theoria and techne and it can only be misleading to characterise moral wisdom in terms of either a moral or a practical science'. (p 324)

Carr's way around this dilemma is to 'embrace fully' the Aristotelian view that practical wisdom (Phronesis) is significantly distinct from both theoretical and technical enquiry' (theoria and techne). And for the development of that principled understanding and deliberation required for the wise conduct of education he encourages a broad understanding of social issues and comments that:

> 'I have long been convinced that students may stand to gain far more from a sympathetic reading of Dickens, Orwell and Lawrence in relation to their understanding of education than they are likely to get from studying Skinner, Bruner or Bloom's taxonomy [but] one is liable to attract the reputation of an educational flat-earther for even hinting at this possibility'. [p 329]

While this is something of an exaggeration I sympathise with this viewpoint, first because it refutes the notion that teaching can be theory driven in a simplistic, prescriptive manner, and second because it emphasises the essential connection that education (and science education) must have with wider sociopolitical issues, that is, with 'real life'. However, there is a place for research informing practice, and practice guiding research, even in the face of the is-ought problem. In science, what 'is' in the real world provides both the basis for the development of theories and the final judgment of them, that is, we theorise about and investigate the behaviour of the world but we cannot will it to behave in a particular way. In education we must start with what 'is' in the real world but then use the ethical judgment of teachers and others to supply the 'ought', that is, to argue how we think things should be and what we should be trying to achieve. There will be limits of all kinds but we need to explore how to push the boundaries of what exists and how to do this within the complex dialectical relationship between teacher, student, knowledge and society.

Despite the acknowledged theory-practice problem, I am by no means opposed to the notion that advances in educational theory are able to inform teachers so that they improve their professional practice. However, this should not be a prescriptive, top-down process. Researchers need to value the detailed skills and craft knowledge of teachers as a rich source of data and, as part of being reflective practitioners, teachers should acknowledge the broader and more detached view of the researcher. Tomanek (1994) makes a case for researchers to study the 'experienced curriculum' at the level of content and the meanings that are shaped during classroom interactions, that is, to study the actual outcomes of science education. In particular she makes a plea not to restrict studies to methodology and then prescribe how teachers should behave. The importance of recognising the craft skills of teachers is also emphasised by Haney et. al. (1996) when, in discussing barriers to progress in reform, they conclude that 'empowering teachers by providing them with both decision-making opportunities and needed resources appears to be central to lasting educational reform'. A potentially profitable approach lies in teachers and researchers working jointly, along the lines recommended by Kyle, Linn, and Bitner et. al. (1991), Shymansky and Kyle (1992) and Linn (1992). A similar sentiment is expressed again by Kyle (1994) when, in reference to the then new Handbook of Research on Science Teaching and Learning - Gabel, D. L. (editor), - he muses that 'perhaps the second edition will celebrate a new vision in which theory and praxis are linked among members of a dialogical community'. However, the most comprehensive and practical proposal is by Lijnse (1995).

Lijnse highlights a basic dilemma. Researchers can report a detailed, well grounded project that involves a teacher and a particular classroom - but this will be non-generalisable, that is, it cannot be easily applied to other specific classrooms because it lacks any theoretical bite. Or, researchers can produce a theoretical piece of research that is abstract and 'generalised' - but this will not be easy to translate into informed classroom practice. To avoid this dilemma, Lijnse sees theory developing from specific studies referred to as scenarios.

> 'A scenario describes and justifies in considerable detail the learning tasks and their interrelations, and what actions the students and teachers are supposed and expect to perform: It can be seen as the description and the theoretical justification of a hypothetical interrelated learning and teaching process. In trying it out and closely monitoring it, it can be put to the test, and consequently revised. In the end, the scenario can be regarded as a rather detailed domain-specific theory for the teaching of a particular topic. Reflection on scenarios for various topics may lead to "higher level"

> theories...The intent is not to "prove" anything but to make it possible for others to judge what has been done and to enable them to "reconstruct" for themselves the processes described.' [p 196]

This acknowledges a more equal partnership between researcher and practitioner, and this is in stark contrast to the idea of curriculum development through the implementation of a fully fledged 'new' scheme (even if there is a well supported scheme of concurrent teacher development).

My model lacks a way of improving content and method decisions. I have simply relied on 'teacher professionalism' and, although Dana et al. and other authors describe clearly how this might be supported, one could legitimately ask how this develops in the first place. What Lijnse's developmental research does is provide a non-prescriptive mechanism for this development, that is it provides a way forward that does not involve implementing 'new' schemes. However, on its own, Lijnse's model has nothing to prevent it from being a lot of isolated 'solutions to problems', that is it lacks a framework. What my model does is provide that framework and allow developmental research to reform science education. At the same time the model allows maximum teacher autonomy, it provides defensible educational outcomes and it supports the rationale of social change.

10.3 Where to Now?

If we are to apply scientific modes of enquiry to the improvement of science education then one thing we might expect to do is to squarely face challenging questions and assertions. For example Dutch (1996) challenges some assumptions about learners' curiosity:

> The fact that modern humans existed for several hundred thousand years without progressing beyond hunter-gatherer technology does not inspire confidence in the idea that curiosity is a hallmark of our species. The curiosity of children is superficial and short-lived: the adult equivalents are pseudoscience, channel surfing, supermarket tabloids, and the ten-second sound bite. The real educational tragedy in America is not that so many outgrow their childlike curiosity, but that so few do.
>
> [p 246].

Matthews (1995) follows a similar theme in objecting to constructivists who propose 'a facile continuity between the activity of children and the activity of scientists' where 'children are proto-scientists and scientists are somewhat older children'. What must be asked is whether constructivists seriously hold that science is by nature 'commonsense', or whether they stress the 'everyday' aspect of science as a pedagogical strategy that makes science more accessible to children.

In stark contrast to the view of science as a very natural activity is the claim by Dutch (1996) that:

> Science, foreign languages, and history are unpopular because they are *hard*, not because they are poorly taught. They require students to focus on things outside the self and learn new modes of thought ... anti-science, math anxiety and science anxiety are largely rooted in narcissism...
> (italics in the original) [p 249]

Do we need to ask whether we do expect too little effort on the part of students when they learn science? or does Dutch mistakenly equate learning with mental pain? Perhaps a balance has been struck by Bereiter, Scardamalia, Cassells and Hewitt (1997). Their report on an exercise with sixth graders describes how, rather than following postmodernists' urge to 'cut scientists down to size', they tried to 'bring students up to size, instead'.

All the above points touch on serious issues about the nature of science and the nature of teaching and learning. They are deserving of equally serious debate, even if it is to discover that on many points the various parties hold similar views but express them differently and so talk past each other. The rationale and model for science teaching described in this thesis makes debates more productive by providing a framework that will help us avoid old mistakes. In his book, Challenging New Zealand Science Education, Matthews (1995) criticises a set of 35 lesson plans because, while most contained 'pleasant enough activities', only two 'were concerned to inform pupils about what food goldfish ate, what temperature water they survive in ...' (p133). In this case, before rushing in to support or condemn Matthews' criticism, we can ask whether or not the activities were part of an integrated programme aimed at producing a measured commitment to some theory. In isolation, individual activities, and even individual lessons, cannot readily be judged good or bad.

Matthews extended his criticism to science education in general and the New Zealand science curriculum in particular. The criticism was so fierce that a rebuttal volume was assembled and distributed by the Waikato science education centre (Bell, 1995). While the debate was overly acrimonious it did have the positive effect of raising the public profile of science education with numerous articles featuring in the major newspapers (see reprints of these in Bell, 1995). When considering these criticisms of the curriculum we must look at the reasons for curriculum change. There was a desire by academics to put into practise the 'constructivist' principles arising from research here and overseas, and there was a political desire on the part of the Minister of Education to gain 'accountibility' through the specification of levels of achievement. However, there was also an expression of dissatisfaction from teachers; the documents from which they were then working were certainly not ideal.

The current science curriculum is a curious document. Its heart and soul come from a non-prescriptive, Form 1 - V science curriculum that was completed in 1990 but never officially released, and its structural form comes from the highly prescriptive, Achievement Initiative set up in the United Kingdom. The result is a very open ended document that is little influenced by the content imperatives of science but one that specifies Achievement Objectives at eight different levels. Despite the plethora of curricula change over the last few years, I believe there is a strong case for reviewing the present curriculum document.

First, the curriculum document is open-ended in terms of the content and method, and while this is a positive feature, there needs to be some sort of guiding principles for structuring learning. If this structure is not provided by science content, then it could be provided by the model of teaching outlined in this paper.

Second, if we are to be open about the content and method, and if we also expect teachers to use professional autonomy effectively, then it is very important that teachers have a clear rationale for teaching science - setting such a rationale has been the major goal of this paper.

Third, if we accept that most primary teachers will not have expert scientific knowledge, then much more explanation [at the teachers level] of the various Achievement Aims is needed. For example, in my experience, there is considerable teacher confusion over what a 'relationship' is [see Ministry of Education, (1993), Aim 2, Physical World strand, p 70]. Furthermore, the curriculum should outline, for each aim, what would be an appropriately sophisticated understanding [at the children's level] at various stages of development. If the aims were explained in this way, we could delete the present 'Levels' of achievement objectives, which are often hopelessly confused over the content and the process. For example, Achievement Objective 1 of the Physical World suggests that 5 and 6 year olds should 'share and clarify their ideas' without any investigation (which is in the next level) and only at upper primary school (Level 4) should children 'compare their ideas with scientific ideas' (Ministry of Education, 1993. pp 72-79). This is clearly a nonsense; children at all levels will need to discuss, clarify, investigate and compare ideas with scientific ones, albeit at differing levels of sophistication.

Fourth, I would remove most of the suggestions for contexts and learning activities [unless they were accompanied by considerable amplification as to which Aim they were related and how this connection was to be established]. In my observation the current vague suggestions lead many well-meaning teachers into ill-considered, non-science topics which make very poor use of the 'science' time allocated in their programme.

Fifth, now that other curriculum documents are established, it is time to look for overlap between curricula and, rather than simply removing any common aims, we should consider fostering integration at the curriculum document level. For example, Physical World, Aim 4 would clearly integrate into a 'technology' topic, and discussions about the ethics of technological applications could easily spill over into 'social studies'. In this way important questions about the applications of science could be discussed. Furthermore, if integration was part of the curriculum documents, it would be clearer to teachers that there was a point where scientific thinking stopped and social studies/ethical thinking began. Curriculum documents should also encourage both reading activities in 'science' and science contexts for 'reading'. We need a carefully thought out policy on integration with attention given to the common and to the distinctive skills of each curriculum area. Such a policy would make it easier for teachers to distinguish, for example, between times when reading is being taught in science and times when science is being taught in reading. If teachers were guided more clearly to examine the skills taught, rather than simply naming a space in their timetable 'science', it could result in more science being taught without any further pressure to fit more into the school day.

In my view, the curriculum document could come down to a smaller and more useful, document that spoke directly to teachers about the broader issues: why we teach science, the special content, skills and thinking that are unique to science, the place of science education within general education, and ways in which science integrates into other planning. This slimmed down curriculum, which would continue to promote professional autonomy within decisions about content and method, would need to be supported with substantial, teacher-friendly resources. And resources do not need to be produced by 'outsiders' or 'experts', many teachers produce great ideas, but these ideas often remain within their school or syndicate. This situation arises, not because teachers do not want to share their ideas, but because teachers often do not realise how good their ideas are. It would be useful to reactivate the previous inspectorial role of giving advice and guidance and of cross-pollenating good ideas. Here is a positive role for ERO!

We also need to consider the areas for research. In a keynote address to the 1999 ESERA conference in Kiel, Peter Fensham claimed that one of the achievements of the past two decades has been the shift in research emphasis to the learner. However, while some shift was necessary, it is possible that the pendulum has swung too far and that there is now a need to refocus both on the teacher and on science. The dilemma that a focus on teaching poses for researchers has been outlined in section 10.2. Such a focus does emphasise the need for researchers to make sense of the complex and messy world of the classroom rather than looking at fragmentary aspects of learning in a controlled environment. Perhaps, for a teacher, the most professionally valuable work a classroom researcher can do is to help the teacher to reflect on their classroom decisions, to articulate a rationale for these decisions, and to analyse the outcome in terms of students achieving a measured commitment to a theory. The second renewed research focus (that on science) could start with a reassessment of prerequisite knowledge for learning various science topics at different levels. With this, I am not advocating a complete return to the type of conceptual analysis behind many of the curricula of the 1960's because these tended to ignore the learner. With hindsight, we may be able to take into account the needs of the learner as well as the content demands. For me, one interesting question that may be answered by such research is whether we can retain a totally open approach to the content or whether there is a need to move to some core of topics. Either way, it seems to me essential that any resource which is designed to help teachers come to grips with science content must itself be carefully structured in terms of the concepts involved.

So, where does this leave primary school science? Where do we go from here? The vast majority of teachers and student teachers that I have met in ten years of teacher training have been highly skilled professionals who would be perfectly capable of teaching good science providing certain conditions were met. These conditions include a curriculum which provides more guidance, the provision of 'user friendly' resources, and the articulation of a clear rationale for teaching science.

This thesis does give a framework consisting of a justification for science education and a model that describes science teaching . With such a framework, advantage could be taken of the 'myriad of possibilities' offered by the curriculum and for this reason I welcome the curriculum's avoidance of prescription. In criticising the current science curriculum let us remember that the previous curricula also failed to provide a coherent framework, and that changes were at least partly in response to teacher dissatisfaction. The new curriculum could work, and science education could move to a higher level of sophistication. It is not that primary teachers have tried to teach science and been found wanting, it is that, within the meaning of this thesis, most primary teachers are yet to try science teaching.

CHAPTER 9. CONCLUSION

The thesis started with the questions of why we teach science, what we should teach in science, and how we should teach it. The key to answering what to teach and how to teach it lies in finding good reasons for why we teach science. Science education, at the level of compulsory science, should be seen in the context of general education, and science education should share general education's broad social goals of building a better society. The form of democracy in most countries exists more in form than in spirit. While general education may teach democratic ideals, capitalist hegemony acts as a brake on the extent to which such ideals can be implemented. In more general terms, action for change is limited by the very nature of humans as social beings - since society preexists any particular individual, intentional human action is moulded by society. However, this does not lead to the inevitable conclusion of social determinism. The set of social relations (which is society) must itself be continually reproduced by the daily actions of people, and this allows for intentional or unintentional effects to occasionally transform parts of society. The rational transformation of society would thus be possible with a population that held democratic ideals, and that had the skills and disposition required to implement those ideals by analysing, challenging and changing social institutions. General education can produce a popular belief in democratic ideals, and science education can play a major role in fostering the skills and dispositions required to implement the ideals.

The general question of 'What is science?' and the more specific question of 'What enables humans to generate reliable knowledge about the world', arose as part of the enquiry into why, how and what to teach. The question 'What is science?' is better replaced by the question, 'How science is becoming?', This replacement is required because science is a relatively new human activity, and it is is not characterised by a simple, fixed method, but rather one that is still evolving. For the purposes of science education, science is best thought of as a way of thinking, a particular way of utilising a human, meaning-making trait, and a conscious search for truth. This view roughly corresponds to a moderate realist view of science and is in contrast to two other alternatives views, positivism and postmodernism. If science education reinforces a positivist view of science then we will limit citizens' critical and analytical attitudes and suppress their justified skepticism. Under these circumstances, citizens will tend to accept information on the basis of authority rather than evidence, and such citizens would be unlikely to challenge and improve society. Post-modernist teaching is even worse as it pushes skepticism to a level where it will destroy people's very belief in 'meta narratives' such as the democratic project.

The nature of scientific knowledge raises questions for teachers of science: 'If science is authoritative, how can we teach it in a non-authoritarian manner?' or 'How can we teach scientific knowledge that is beyond reasonable doubt, but at the same time maintain a healthy skepticism in our students?' The answer lies in aiming to produce in learners a 'measured commitment' to theories. Holding a theory in a measured way means that learners have accepted it, having weighed evidence and other theories against it. Having a commitment to the theory means that, with it, learners will expect to be able to explain new phenomena, to absorb new evidence and will expect it to be more than a match against competing theories. Learning science involves students in changing commitment to a theory and in judging when this is appropriate. This illustrates the difference between learning science and doing science - in the learning situation, teachers can make sensitive use of the authority of science to help children make a rational reassessment of theory commitment. In working this way teachers must distinguish carefully between induction into science and indoctrination into science.

The quality of educational outcomes largely depends on the quality of decisions made by teachers. A curriculum that prescribes either content or method actually puts barriers in the way of teachers as they attempt to respond to the 'dilemmas'. A dilemma occurs when teachers face legitimate but conflicting educational demands caused by the complex internal and external interactions of people, school and society. For such dilemmas, neither educational theory nor curriculum requirements are able to provide solutions. A model is developed in which teaching episodes are represented by points in a space defined by the three dimensions; content selected to be taught, method chosen to teach it and the reason why it is being taught. As long as teaching has the goal of getting children to make a measured theoretical commitment, there is considerable scope for teachers to use their 'local knowledge' and 'teacher wisdom' in deciding what to teach and how to teach it.

Research also has a place in helping determine teacher action but, because teacher decisions and actions rely heavily on local knowledge, a prescriptive model for research (with a hierachy placing researchers above teachers) must be avoided. One appropriate research model is developmental research, a form of cooperative research where theory evolves through a series of 'scenarios'. Such a research programme could promote the desired teaching outcomes by adding to the teaching model a non-prescriptive mechanism for advancing teacher wisdom. In return, my model adds to developmental research a coherent framework that prevents the scenarios from remaining fragmentary answers to isolated questions.

An analogy used in Chapter 9 casts teachers as drivers on a journey which is only partly mapped out. The notion of a partial picture applies to all aspects of social development. In particular, compulsory schooling is a relatively new phenomenon. Set up partly in response to liberal concerns for the fate of children in the new industrial setting, and partly in response to the new industrial demands for a more literate work force, schools have always been torn in two directions. Even where schools reproduce the existing social relations, there is always the potential for education to promote change. The calendar may show tomorrow as just one more square on a preordained chart, the teacher's plan book and timetable may make the year seem like a well-worn track, but events are not entirely predictable. Each time we teach a class we move, minute by minute, into uncharted territory where we cannot forecast exactly the consequences our actions. My hope is for a science education that has change as an integral part of its goals, and for science teachers to take part in the type of change process described by Gramsci:

> For a mass of people to be led to think coherently ... about the real, present world, is a 'philosophical' event far more important and 'original' than the discovery by some philosophical 'genius' of a truth which remains the property of small groups of intellectuals ... it is not a question of introducing from scratch a scientific form of thought into everyone's individual life, but of renovating and making 'critical' an already existing activity.
>
> Antonio Gramsci
> quoted in Willis (1978)
> p 185

We need to start a journey somewhere. We can start by sorting out where we are going and where we should be going, we can start by reflecting on how we could do things better but, if we want change, the key thing is that we should start. In Willis' own words, it may be Monday morning but 'Monday morning need not imply an endless succession of the *same* Monday morning'.[Italics in the original]

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